UTILIZATION OF RED MUD AND POND ASH FOR CONSTRUCTION OF EMBANKMENTS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

CIVIL ENGINEERING

By

PRALOY KUMAR GHOSH

Department of Civil Engineering

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Rourkela-769 008

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CERTIFICATE

This is to certify that the thesis entitled, "**Utilization of Red Mud and Pond Ash for Construction of Embankments**" submitted by Praloy Kumar Ghosh in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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An assemblage of this nature could never have been attempted without reference to and inspiration from the works of others whose details are mentioned in reference section. We acknowledge my indebtedness to all of them. Last but not the least to all of my friends who were patiently extended all sorts of help for accomplishing this undertaking.

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ABSTRACT

One of the major challenges before the processing and manufacturing industries is disposal of the residual waste products. Pond ash and red mud are one of the major waste products of any aluminum industry. The pond ash and red mud sample are acquired form BALCO, Korba where they are disposed off using the Thick Slurry Disposal System, which enables quick consolidation of the slurry once disposed at the ash and red mud pond sites. The project work focuses on the suitability of pond ash and red mud obtained hereby to be used for construction of embankment.

The ash and red mud samples are characterized and analyzed for the various geotechnical properties. The various experimental works include in situ density test using core cutter method, Standard Proctor density test to obtain the maximum dry density and optimum moisture content, and specific gravity test. Using the OMC and MDD results, Direct Shear Box test and Triaxial tests of the samples were carried out in 2-D and 3-D load conditions to obtain the shear strength parameters, c and Φ. The samples were also tested for their permeability characteristics using both falling head and constant head permeameter to obtain the coefficient of permeability, κ.

After characterization of the ash and red mud samples for their individual geotechnical parameters, the samples were mixed in various proportions to get a mix having optimum characteristics. The samples were mixed in the proportions of 90%-10%, 80%-20%, 70%-30%, 60%-40%, 50%-50% of red mud and ash content respectively. All the above experiments were carried out on each mix to obtain an optimum mix. The results of the experiments are all compiled in graphical form to observe the trends in the various parameters. Out of the all, the

optimum mix is found out taking into account the considerations for construction of an embankment.

To account for the experimental findings, the samples were also observed under SEM (Scanning Electron Microscope). The magnified photographs of the particles, their arrangements and the mineralogical constitution are observed under the SEM and analyzed to validate the geotechnical parameters found from experimental procedures. From the analysis of the mineralogical data, presence of some toxic elements is observed. The above analysis and results can help in solving the problem of ash and red mud disposal and to a great extent help in increasing the economic benefit of the alumina industries.

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Chapter 1

INTRODUCTION

One of the major challenges before the processing and manufacturing industries is disposal of the residual waste products. Out of the various production industries, the ore dressing and mineral processing industries are the major contributors towards disposal of toxic waste products. Of all, present emphasis has been laid on the residual products of aluminum industries (Pond Ash and Red Mud) which utilize bauxite (Al_2O_3) as raw material to extract Al out of it. Out of total aluminum production, India contributes only about 3% of the total world's production. The major aluminum producers in India are HINDALCO, INDAL, NALCO, BALCO and MALCO. Added to this, in the absence of any technology that can utilize the industrial wastes like ash and red mud, the industries have to incur heavy expenses in terms of land and space, economy and government and international environmental norms which causes comprehensive reduction in the profit margin . This calls for an effective, economic and environment friendly method to combat the disposal of the waste produced by these industries. One of the most common and feasible way to utilize the waste ash and red mud is to go for construction of embankments with the materials. This project work on Ash and Red Mud aims at characterization of the materials through laboratory experiments, analyzing the various aspects of their geotechnical behavior and hence find the optimum mix of ash and red mud which can serve better for the purpose of embankment construction.

The Pond Ash and Red Mud are residual waste products of aluminum extraction industry. The present samples are obtained from ash ponds and red mud ponds from BALCO, Korba. Both the Ash and Red Mud are collected from Thick Slurry Disposal System. This system has the advantage over conventional thin slurry disposal system that the rate of consolidation of disposed materials in the ponds is quite faster. It takes maximum of 24 hours to consolidate and the deposit hardens to the extent that it is able to walk over the surface on account of lesser water content and certain chemical treatment undergone before the disposing. The present samples are collected from Ash Pond No.3 and Red Mud Pond No.7, BALCO, Korba.

The samples collected from the site are tested to characterize the geotechnical properties of both red mud and ash individually. Tests are conducted to obtain optimum moisture content (OMC), maximum dry density (MDD) using Standard Proctor test, the shear strength parameters c and Φ, both under 2-D and 3-D loading conditions using Direct Shear Box and Triaxial test respectively. The permeability tests are also conducted under constant head and falling head conditions to obtain the coefficient of permeability, κ. All these tests are repeated twice (thrice in some cases) to obtain concordant results and cross check the findings again and again. After the individual parameters are obtained, the next step is to obtain the optimum mix of red mud and ash so as to get the best result of the mix. To attain optimization, red mud and ash samples are mixed and tested by hit and trial basis. The mixes constituted red mud proportion varying from 90% to 50% at interval of 10% and the rest of the mix being ash. The mixes formed hereby are tested for all the above parameters to obtain the optimum mix keeping forth the requirements for construction of embankment.

To validate the experimental findings, the samples are studied under Scanning Electron Microscope (SEM) to get magnified photographs of the particles and their interaction when mixed in various proportions. The samples are also studied to obtain the mineral composition (in % by weight) to analyze the effect of various chemical compounds in the geotechnical parameters like density and shear strength. The ecological impact of the embankment are also studied under leaching test to observe the minerals likely to get washed out due to leaching under natural precipitation conditions and hence get deposited in the local water bodies thereby contaminating them.

Chapter 2

LITERATURE REVIEW

2.1 Pond Ash: An Overview

Ash is the primary waste product and residue obtained by burning of coal. The ash formed is disposed by mixing it with water and certain chemicals to render it eco friendly in the ponds. These ponds are called ash ponds. The ash sample used in this project is obtained from BALCO, Korba. This plant uses coal as fuel for its alumina extraction from bauxite as ore. The disposal system used in this plant is called Thick Slurry Disposal System which uses certain chemical treatment that renders quick consolidation of the ash slurry as soon as it is deposited at the site. The chemical, geotechnical and mineralogical features of ash depend on various factors like:

i. Type of coal used for fuel.
ii. Degree of combustion.
iii. Disposal system used.

The coal obtained from mines can be categorized as:

i. Grade A
ii. Grade B
iii. Grade C
iv. Grade D

The above classification of Indian coal is based on the carbon content, the maximum being in case of Grade A and the minimum being for Grade D. Thus the quantity of ash produced varies according to the grade of coal used for combustion. A coal having maximum carbon content will produce minimum ash and vice versa. The mineralogical aspect of ash varies according to the degree of combustion of coal. For completely burnt coal, the ash primarily consists of P, Al, Fe and Si along with volatile elements. On the other hand, for partially burnt coal, like the one used for production of coke, used in Bayer's process for alumina production, will consist of C also as residue.

The chemical composition of disposed ash is also affected by the disposal system. The conventional Thin Slurry Disposal System uses minimal chemical treatment. The ash particles are lighter and it takes several days to consolidate in the pods after being disposed. This system is used in case of most of the manufacturing industries for ash disposal. The other system, as mentioned above, is Thick Slurry Disposal System, uses chemical treatment that causes aggregation of ash particles causing them to be relatively heavier. Also the water content of the slurry is also reduced compared to that of the former system. Due to heavier particles and reduced water content, the slurry disposed consolidates very quickly, within about 24 hrs. of disposal.

Pond ash has been successfully characterized and used in construction of embankments (Bera Ashis Kumar, Ghosh Ambarish and Ghosh Amalendu, 2007). Efforts have been made successfully to work with pond ash mixed with soil and hardener to study upon its compaction characteristics and hence utilize the same for the purpose of embankments (Kumar Virender, 2004). Efforts have also been made successfully to utilize pond ash from steel plants for manufacture of bricks of superior quality (Pandey, Piyush Kant and Agrawal Raj Kumar October, 2002). Pond ash has also been mixed with lime and the characteristics of lime stabilized pond ash have also been studied for its strength parameters along with durability aspects which show its potential to be used as embankment construction material. (Chand Sudeep Kumar, Subbarao Chillara, July 2007).

2.2 Red Mud: An Overview

Red Mud is produced during the Bayer Process. With this process, we can extract the aluminum (oxy) hydroxides from bauxites and get alumina, which eventually can be smelted and give aluminum. It is the insoluble product after bauxite digestion with sodium hydroxide at elevated temperature and pressure. It is a mixture of compounds originally present in the parent mineral, bauxite, and of compounds formed or introduced during the Bayer cycle. It is disposed as a slurry having a solid concentration in the range of 10-30%, pH in the range of 13 and high ionic strength.

A chemical analysis would reveal that RM contains silica, aluminum, iron, calcium, titanium, as well as an array of minor constituents, namely: Na, K, Cr, V, Ni, Ba, Cu, Mn, Pb, Zn etc. The variation in chemical composition between different RMs worldwide is high. Mineralogically, RM has a very high number of compounds present. The more frequent addressed are:

Hematite (Fe_2O_3), goethite $Fe_{(1-x)}Al_xOOH$ (X=0-0.33), gibbsite $Al(OH)_3$, boehmite AlO(OH), diaspore AlO(OH), calcite ($CaCO_3$), calcium aluminum hydrate ($x.CaO.yAl_2O_3.zH_2O$), quartz (SiO_2), rutile (TiO_2), anatase (TiO_2), $CaTiO_3$, Na_2TiO_3, kaolinite $Al_2O_3.2SiO_2.2H_2O$, sodalites, aluminum silicates, cancrinite hydroxycancrinite, chantalite, hydrogarnet. A wide variety of organic compounds are also present.

These organic compounds, giving RM a distinctive odour, are derived largely from decomposed vegetation and roots. Under the alkaline oxidative conditions existing in the Bayer process, they break down to more simple compounds such as the sodium salts of succinic, acetic and oxalic acids. Predominant among these salts is sodium oxalate.

RM is a very fine material in terms of particle size distribution. Typical values would account for 90 volume % below 75μm. The specific surface (BET) of RM is around $10 m^2/g$.

As it is apparent RM is a highly complex material that differs due to the different bauxites used and the different process parameters. Therefore RM should be regarded as a group of materials, having particular characteristics, such:

i. Produced during the Bayer process
ii. Water suspensions and highly alkaline
iii. Mainly composed of iron oxides and have a variety of elements and mineralogical phases
iv. Relatively high specific surface/fine particle size distribution.

Agrawal *et al*. provide a table, where the details of the RM disposal practices, after Prasad PM *et* *al.* at the Indian alumina plants are summarized:

Table 2.3.1 Red Mud Disposal Practices At Indian Alumina Plants

Red mud disposal practices at the Indian alumina plants

Serial number	Name of the plant	Plant capacity (t)	Red mud (t/t) of alumina	Dumping procedure
1	INDAL, Muri	72,000	1.35–1.45	This refinary adopted the closed cycle (wet slurry) disposal system (CCD). The disposal ponds have not been provided with any liner.
2	INDAL, Belgaum	2,20,000	1.16	The plant switched over to dry disposal mode from wet slurry disposal mode in 1985. The mud after clarification passes through six stage counter current washing and after filtration (65% solids), it is disposed off by dumpers at the pond site. The dry portion of the pond is covered with a 15 cm black cotton soil for promoting green vegetation.
3	HINDALCO, Renukoot	3,50,000	1.4	Traditional CCD method of impoundment was used. In late 1979 dry disposal method was implemented. After five stages counter current washing the solid is filtered (70% solids) and disposed off into the pond.
4	BALCO, Korba	2,00,000	1.3	Residue after settling, counter currently washed in four stages and filtered. The filtered cake is repulped with the pond returned water and dumped in the pond. Uses modified CCD system of disposal. The dykes of the currently used pond have stone masonry and well protected polythene liner and clay layer.
5	NALCO, Damonjodi	8,00,000	1.2	A modified CCD method is used for disposal. Subjected to six stage counter current washing by pond returned water (0.5 g/l Na_2O) and condensate from the evaporators. The washed red mud is repulped and sent to disposal sites. The bottom and sides of the pond are covered by impervious and semi pervious clay with base filters.

CCD: closed cycle disposal; MCCD: modified CCD; DS: dry stacking.

Studies on red mud have been carried out mainly to figure out the environmental impact of it. To assess the environmental impact of red mud, thorough chemical analysis of red mud has been carried out (Patel, C. B., Jain, V. K., Pandey, G. S. 1986, Hind A. R., Bhargav S. K., Grocott

Stephen C., 1999). The red mud characteristics vary from place to place depending on the alumina extraction process and method of disposal. Efforts have also been made to characterize the Indian red mud, but the characterization is limited to chemical analysis (Prasad P. M. and Sharma J. M., 1986). An effort has been made previously to obtain optimum mix for Australian Red sand, lime kiln dust and fly ash for use of the optimum mix in highway pavement filling materials (Jitsangiam, P., Nikraz, H., and Jamieson, E., 2007). The optimum mix obtained in this research work was 70% Red Sand + 25% fly ash + 5% Lime kiln dust.

2.3 Problem Statement

The purpose of the project is characterization of red mud and pond ash collected from aluminum industry, BALCO, Korba. The project also aims at finding out the optimum mix proportion of red mud and ash so as to utilize the same for construction of embankments.

The key objectives can be enumerated as:

i. Characterization of Red Mud and Pond Ash.
ii. Obtaining optimum mix of Red Mud and Pond Ash aiming for construction of embankments.

2.4 Experimental Setups

2.4.1 Standard Proctor Test (IS: 2720 Part VII 1980/87)

The test equipment consists of:

i. Cylindrical metal mould having an internal diameter of 100 mm, an internal effective height of 127.5 mm and an effective volume of 1000 ml.
ii. Detachable base plate.
iii. Collar 60 mm in effective height.
iv. Rammer 2.6 kg in mass falling through a height of 310 mm.

The test consists in compacting soil at various water contents in the mould, in three equal layers, each layer being given 25 blows of the 2.5 kg rammer dropped from a height of 30.5 cm. The dry density obtained in each test is determined by knowing the mass of the compacted soil and its water content. The compactive energy used for this test is 6065 kg cm per 100 ml of soil.

About 2.5 kg of oven dried soil; passing through 4.75 mm sieve is taken and thoroughly mixed with water. The quantity of water to be added initially depends upon the probable optimum water content for the soil. The initial water content is taken about 4% for the used samples of ash and red mud. The empty mould attached with the base plate is weighted without the collar. The collar is then attached to the mould. The mixed and matured soil is placed in the mould and compacted by giving 25 blows of the rammer uniformly distributed over the surface, such that the compacted height of the soil is about 1/3 the height of the mould. The second and third layers are similarly compacted, each layer being given 25 blows. The last layer should not project more than 6 mm into the collar. The collar is removed and the top layer is trimmed off to make it level with the top of mould. The weight of the mould, base plate and the compacted soil is taken. A representative sample is taken from three different layers of the mould, one from the top layer, other from the middle section and the third from the bottom section of the mould, and kept for water content determination. The bulk density and the corresponding dry density for the compacted soil are calculated from the following relations:

$$\rho = M/V \text{ (g/cc); and}$$

$$\rho_d = \rho/(1+w) \text{ (g/cc);}$$

Where, ρ = bulk density of the soil (g/cc),

ρ_d = dry density of the soil (g/cc),

M = mass of the wet compacted specimen (g),

w = water content (ratio),

V = volume of the mould, 1000 ml.

The compacted soil is taken out of the mould and remixed with raised water content (by 4%). After allowing mixing and maturing, the soil is compacted in the mould in three layers again and the corresponding dry density ρ_d and water content w is determined. The test is repeated with increasing water contents, and the corresponding dry density obtained is thus determined. A compaction curve is plotted between the water content as abscissa and the corresponding dry densities as ordinates. The dry density goes on increasing till the maximum density is reached. This density is called maximum dry density (MDD) and the corresponding moisture content is called optimum moisture content (OMC).

2.4.2 Direct Shear Box Test

This test is the simplest test and is used to find the shear strength parameters, the cohesion c and the angle of internal friction Φ in 2-D loading conditions. The test is performed in a shear box apparatus. The apparatus consists of a two piece shear box of square or circular cross section. The lower half of the box is rigidly held in position in a container which rests over slides or rollers and which can be pushed forward my a geared jack driven either by electric motor or by hand. The upper half of the box butts against a proving ring. The soil sample is compacted in the shear box and is held between metal grids and porous plates. Normal load is applied on the specimen from a loading yoke bearing upon steel ball of pressure pad. When a shearing force is applied to the lower box through the geared jack, the movement of the lower part of the box is transmitted through the specimen to the upper part of the box and hence on the proving ring. The deformation of the proving ring indicates the shear force.

The specimen of the shear box is sheared under normal load N. the shearing strain is made to increase at a constant rate, and hence the test is also called as strain controlled shear box test. The other type of test is called stress controlled shear box test in which there is an arrangement to increase the shear stress at a desired rate and measure the shearing strain. The shear force, F, at failure corresponding to normal load N is measured with the help of the proving ring. A number of identical specimens are tested under increasing normal loads and the required maximum shear force is recorded. A graph is plotted between the shear force F (τ) as ordinate and the normal load N (σ) as the abscissa. Such a plot gives the failure envelope of the specimen under the testing conditions. Any point (σ, τ) on the failure envelope represents the state of stress in the material during failure, under a given normal load.

Tests can be performed under all three drainage conditions.

i. To conduct Unconsolidated Undrained (UU) test, plain grids are used.
ii. For Consolidated Drained (CD) tests perforated grids are used. The sample is first consolidated under the normal load and then sheared sufficiently slowly so that complete dissipation of the pore pressure takes place.
iii. For the Consolidated Undrained (CU) tests, perforated grids are used. The sample is permitted to consolidate under the normal load. After the completion of consolidation, the specimen is sheared quickly in about 5 to 10 minutes.

However the test has the following disadvantages:

i. The distribution of the normal stress and the shear stress over the potential surface of sliding is not uniform. The stress is more at the edges and less in the centre. Due to this there is a progressive failure of the specimen, thus the entire strength of the soil is not mobilized simultaneously.
ii. As the test progresses, the area under stress gradually decreases.
iii. As compared to triaxial test, there is a little control over the drainage of the soil.
iv. The plane of shear failure is predetermined, which may not be the weakest one.
v. There is effect of the lateral restraint of the side walls of the shear box.

In spite of the above the direct shear box test is a simple effective test. The relatively thin thickness of the sample allows quick drainage and quick dissipation of pore pressure developed during the test.

2.4.3 Triaxial Shear Test

In this test, the solid specimen, cylindrical in shape is subjected to direct stresses in three mutually perpendicular directions. In the common solid cylindrical specimen test, the major principal stress σ_1 is applied in the vertical direction and the other two principal stresses σ_2 and σ_3 ($\sigma_2 = \sigma_3$) is applied in the horizontal direction by the fluid pressure round the specimen.

The test equipment consists of high pressure cylindrical cell made of Perspex or any other transparent material, fitted between the base and the top cap. Three outlet connections are generally provided through the base:

i. Cell fluid inlet.

ii. Pore water outlet from the bottom of the outlet.
iii. The drainage outlet from the top of the specimen.

A separate compressor is used to apply fluid pressure inside the cell. A stainless steel piston running through the center of the top cap applies the vertical compressive load (called the deviator stress) on the specimen under test. The load is applied through a proving ring with the help of a mechanically operated load frame. Depending upon the drainage conditions of the test, solid non porous disc or end caps or porous discs are placed on the top and the bottom of the specimen and the rubber membrane are sealed on to these end caps by rubber rings.

The length of the specimen is kept to about 2 to 2½ times its diameter. The cell pressure $\sigma_2=\sigma_3$ acts all round the specimen; it also acts on the top of the specimen as well as on the vertical piston meant for applying the deviator stress. The vertical stress applied by the loading frame, is equal to $(\sigma_1-\sigma_3)$ so that the total stress on the top of the specimen = $(\sigma_1-\sigma_3) + \sigma_3 = \sigma_1$ = major principal stress. This principal stress difference $(\sigma_1-\sigma_3)$ is called deviator stress recorded on the proving ring dial. Another dial measures the vertical deformations of the sample during the test.

A particular confining pressure σ_3 is applied during one observation, giving the value of other stress σ_1 at failure. A Mohr's circle corresponding to this set of (σ_1, σ3) can thus be plotted. Various sets of observations are taken for various confining pressures σ_3 and the corresponding σ_1 are obtained. Thus a number of Mohr's circles corresponding to failure conditions are obtained. A curve tangential to these stress circles gives the failure envelope for the soil under the given drainage conditions of the test.

Shear tests can be performed in the triaxial apparatus under all three drainage conditions. For undrained test (UU) solid non-porous end caps are placed on the top and bottom of the specimen. In the consolidated undrained test (CU), porous discs are used. The specimen is allowed to consolidate under the confining pressure by keeping the pore water outlet open. When the consolidation is complete, the pore water outlet is closed and the specimen is sheared under undrained condition. In the drained test, the pore water outlet is kept open throughout the test. The compression test is carried out sufficiently slowly to allow for the full drainage during the test.

2.4.4 Permeability Test

Permeability is the characteristic of a porous material by virtue of which it permits the passage or seepage of water (or other fluid) through its interconnected voids. In most of the practical problems of flow through soil, flow is considered to be laminar. The study of seepage of water trough soil is done because:

i. Determination of rate of settlement of a saturated compressible soil layer.
ii. Calculation of seepage through the body of earth dams, and stability of slopes.
iii. Calculation of uplift pressures under hydraulic structures and their safety against piping.
iv. Ground water flow towards well and drainage of soils.

The permeability characteristics of soil can be defined using Darcy's law.

According to Darcy's law, the rate of flow or discharge per unit time is proportional to the hydraulic gradient. Mathematically, $q = \kappa.i.A$

Where; q = discharge per unit time.

A = total cross sectional area of the soil mass.

i = hydraulic gradient

κ = Darcy's coefficient of permeability.

If a soil sample of length L and cross sectional area A, is subjected to differential head of water, $h1 - h2$, the hydraulic gradient i will be $(h1 - h2)/ L$ and ,

$$q = \kappa.\ A.\ (h1 - h2)/L$$

Thus, the coefficient of permeability is defined as the average velocity of flow that will occur through the total cross sectional area of soil under unit hydraulic gradient. The dimension of coefficient of permeability is same as that of velocity and is usually expressed as cm/s or m/day. The coefficient of permeability of a given soil specimen can be found out by two methods:

i. Constant head permeability test.
ii. Falling head permeability test.

Chapter 3

CHARACTERIZATION OF POND ASH

3.1 In situ Density

The in situ density of pond ash is obtained by core cutter method. The samples are collected in the core cutter mould and brought from the site. The open faces of the mould were sealed with a thin layer of wax to prevent loss of moisture in the transit of the moulds from site to the laboratory. Two core cutter moulds were taken from the site to obtain a concurrent value of the in situ density. The following observations are obtained from the core cutter analysis:

Sample I

Total weight of core cutter and ash = 3174 gm

Weight of mould = 1797 gm

Diameter of mould = 10.3 cm

Height of mould = 15.3 cm

Hence, in situ wet density of ash = (3174 - 1797)/ (π x 10.3^2 x 15.3/4)

= 1.08 gm/cc

Dry density = 0.98 gm/cc

In situ moisture content = 33.7%

Sample II

Total weight of core cutter and ash = 3208 gm

Weight of mould = 1810 gm

Diameter of mould = 10.4 cm

Height of mould = 15.3 cm

Hence, in situ wet density of ash = (3208 - 1810)/ (π x 10.3^2 x 15.3/4)

= 1.07 gm/cc

Dry density = 1.01 gm/cc

In situ moisture content = 28.3%

3.2 Standard Proctor Test

Standard proctor test are conducted on Pond sample to obtain the maximum dry density (MDD) and the corresponding optimum moisture content (OMC). The test is conducted on oven dried ash samples. The volume of the mould used is 1000 cc.

The plot of dry density against the moisture content is as follows:

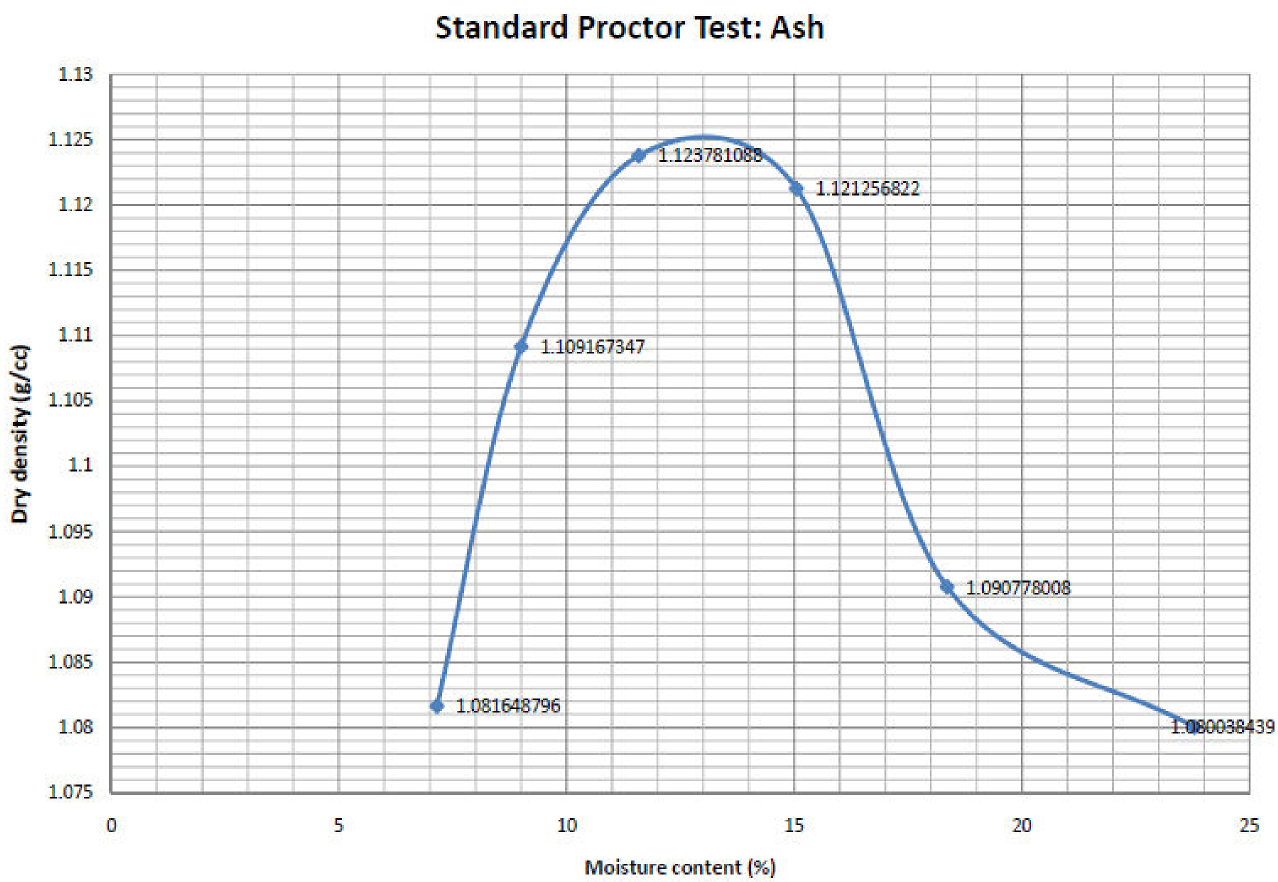


Fig. 3.2.1 Standard Proctor Test: Ash

From the above plot, the maximum dry density (MDD) is found to be 1.12 gm/cc and the optimum moisture content required to obtain the same is 11%.

3.3 Direct Shear Box test

To obtain the shear strength characteristic of the ash specimen, direct shear tests were conducted on the samples. The test specimen is prepared by calculating the volume of the shear box and hence finding the mass of dry specimen required for test using the maximum dry density (MDD) obtained from standard Proctor test. The water content is kept equal to the optimum moisture content (OMC), also obtained from standard proctor test. The test has been repeated twice to obtain satisfactory results.

Dimension of Shear Box: 6 cm x 6 cm x 2.2 cm

The failure envelope is obtained for three normal loads of 5 lb. 10 lb and 15 lb.

The observations for the direct shear test for ash is as follows:

Table 3.3.1 Direct Shear Test: Ash

Direct shear test

Sample : Ash

OMC = 11%

MDD = 1.12 g/cc

Mass of ash required = 1.12 x 79.2

= 88.70 gm

Normal load(lb)	Normal load(N)	Proving Ring reading	Shear load(N)
5	111.13	27	101.75
10	222.26	47	177.12
15	333.39	67	252.49

The plot of the failure envelope on the basis of the above observations is as follows:

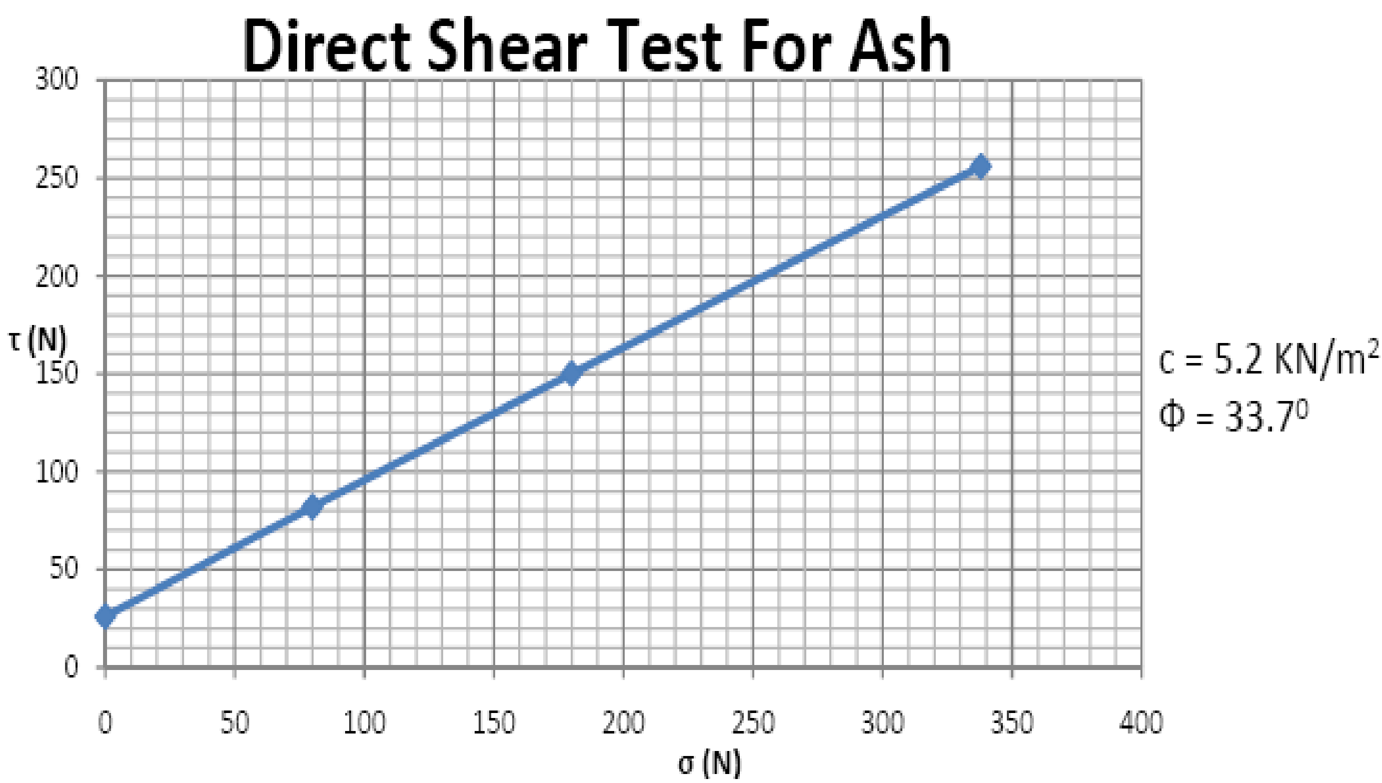


Fig. 3.3.1 Direct Shear Test: Ash

From the failure envelope obtained above, the shear strength parameters of ash are:

$c = 7.7\ KN/m^2$;

$\Phi = 33.7^0$

3.4 Triaxial test

To obtain the shear parameters under 3-d loading conditions, triaxial test is conducted on the ash. To conduct triaxial test, cylindrical samples are made and put in the triaxial chamber. The dimension of the sample is as follows:

Diameter of specimen = 5.1 cm

Height of specimen = 9.4 cm

The triaxial test is conducted under unconsolidatated undrained condition. To obtain the above drainage condition, the sample is covered by membrane and impervious Perspex discs are placed on both the open ends and tied to the membrane tightly using rubber bands.

The triaxial tests are conducted under cell pressures of 0.6 Pa, 0.8 Pa and 1.0 Pa to obtain three sets of Mohr's circle of stresses and hence plot the failure envelope and the whole set of experiment has been repeated thrice to obtain results.

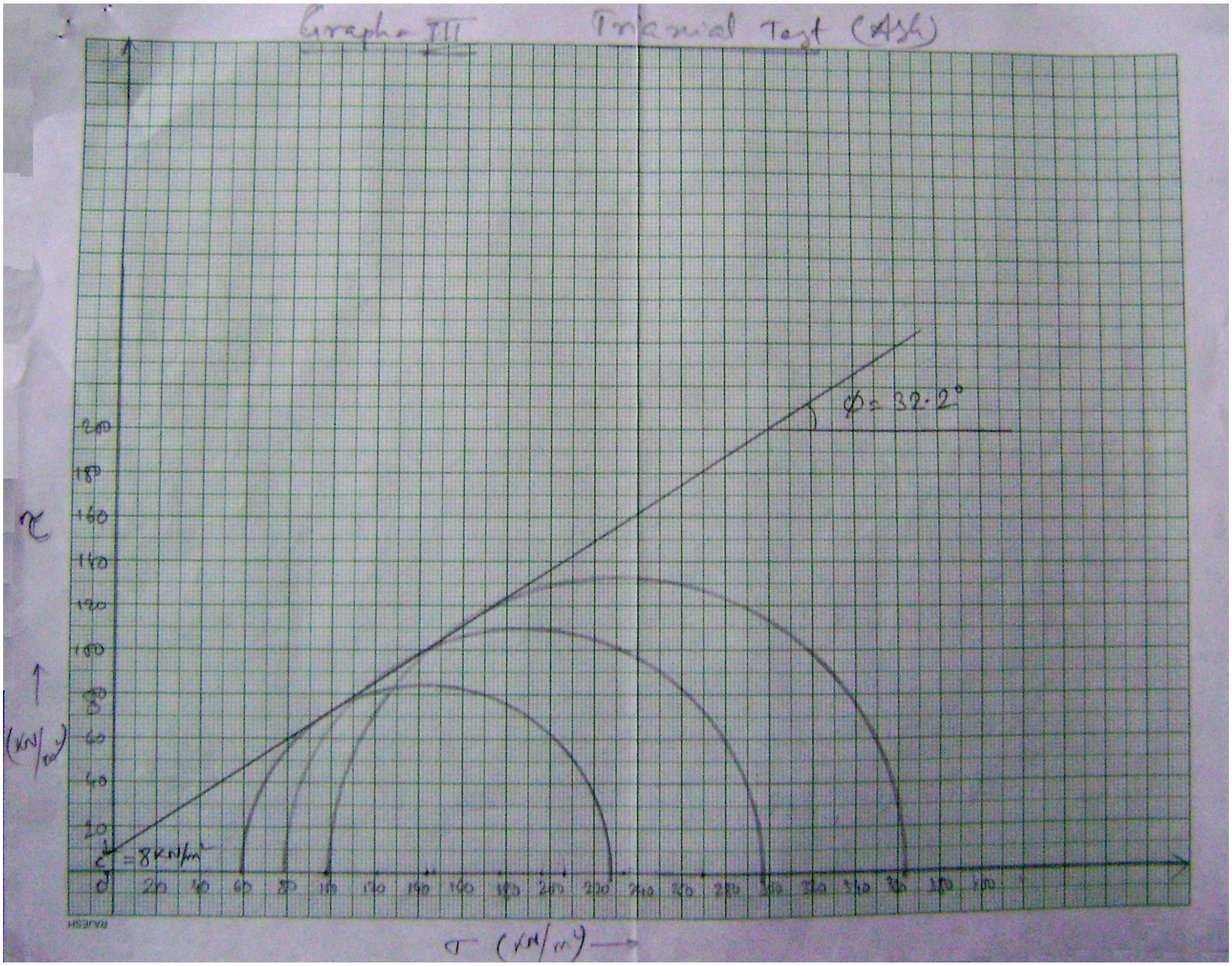


Fig. 3.4.1 Triaxial Shear Test: Pond Ash

From the failure envelope, the shear strength parameters of ash under triaxial loading conditions are:

c = 8.0 KN/m^2

Φ = 32.2^0

3.5 Permeability Test

3.5.1 Constant Head Permeability Test

The coefficient of permeability of the ash if found out by constant head permeameter. The observation of the constant head permeameter test is as follows:

Diameter of mould, d = 11 cm

Height of mould, h = 13.8 cm

Volume of mould = 1311.45 cc

Weight of ash required = 1311.45 x 1.12

= 1468.83 gm

The sample of ash filled in the mould is allowed to saturate fully before performing the test.

Table 3.5.1 Constant Head Permeability Test

H (cm)	L (cm)	Hydraulic gradient, *i*	A (cm^2)	Vol. of water (ml)	Time taken to collect water, t (sec)	Coefficient of permeability, κ (cm/s)
13.8	1.0	0.081	95.03	5	690	8.03e-7
13.8	1.8	0.081	95.03	5	900	8.47e-7

Thus the average coefficient of permeability of ash under constant head permeability is found out to be 8.25e-7 cm/s.

3.5.2 Falling Head Permeability test

The coefficient of permeability of the ash specimen is also found out using falling head permeameter. The observations for falling head permeameter test are as follows:

Diameter of mould, d = 11 cm

Height of mould, h = 13.8 cm

Volume = 1311.45 cc

Weight of ash required = 1311.45 x 1.12

= 1468.83 gm

Table 3.5.2 Falling Head Permeability Test

Initial head, h1(cm)	Final head, h2(cm)	Volume of water, V (ml)	Time taken to collect, t (sec)	Area of cross-section, A (cm2)	a (cm2)	Coefficient of permeability, κ (cm/s)
80.5	40.5	17	226	95.03	1.88e-3	8.29e-7
100	60	18	183	95.03	2.4e-3	8.7e-7

Thus the coefficient of permeability of ash is found out to be 8.49e-7 cm/s.

3.6 Specific Gravity test

The specific gravity of ash is obtained as 2.24.

3.7 Mineralogy test

The mineralogy analysis and the particle arrangement of oven dry ash samples are carried out under Scanning Electron Microscope (SEM). The constituent of various minerals and their proportions in % by weight is as follows:

Table 3.7.1 Mineralogy: Pond Ash

Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
C K	9.40	0.4164	20.95	2.48	29.95
O K	52.52	1.0263	47.49	1.67	50.97
Al K	11.07	0.9983	10.29	0.47	6.55
Si K	19.46	0.9304	19.41	0.77	11.87
K K	0.77	1.0088	0.71	0.18	0.31
Fe K	0.98	0.7872	1.15	0.38	0.35
Totals			100.00		

The proportion of different constituent minerals is graphically plotted as follows:

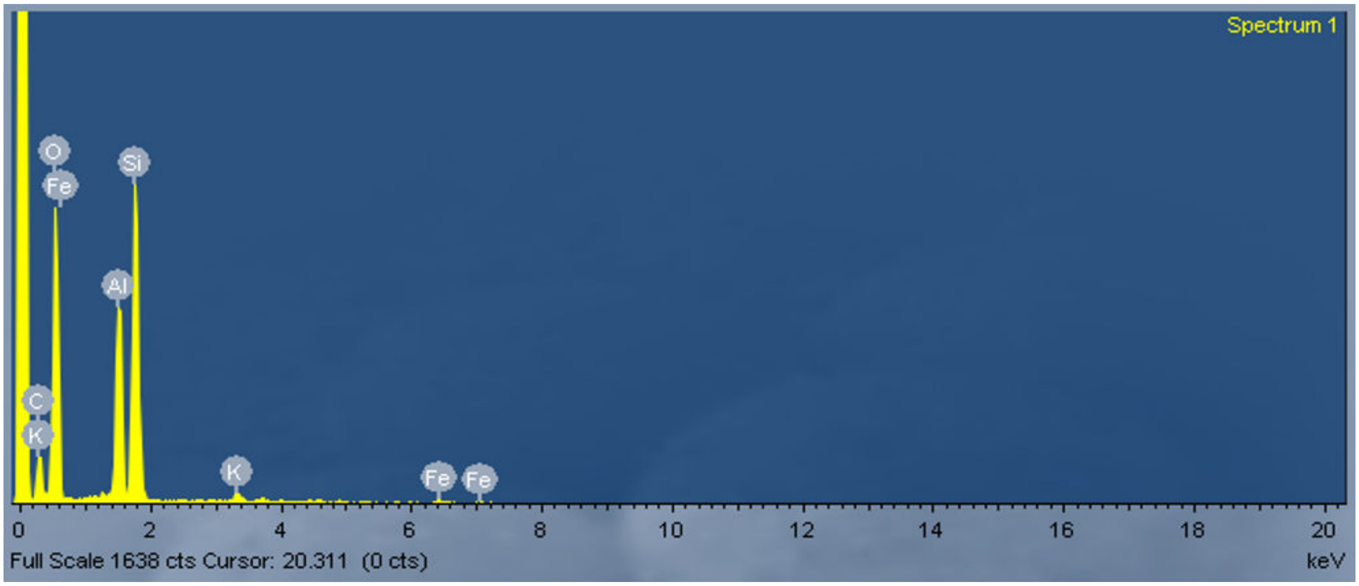


Fig. 3.7.1: Proportion of minerals: Pond ash

The arrangement of particles in the specimen is viewed at a magnification of 5500 at 15 kV under the scanning electron microscope in a pressure of 50 pa. The photograph of the magnified view is as follows:

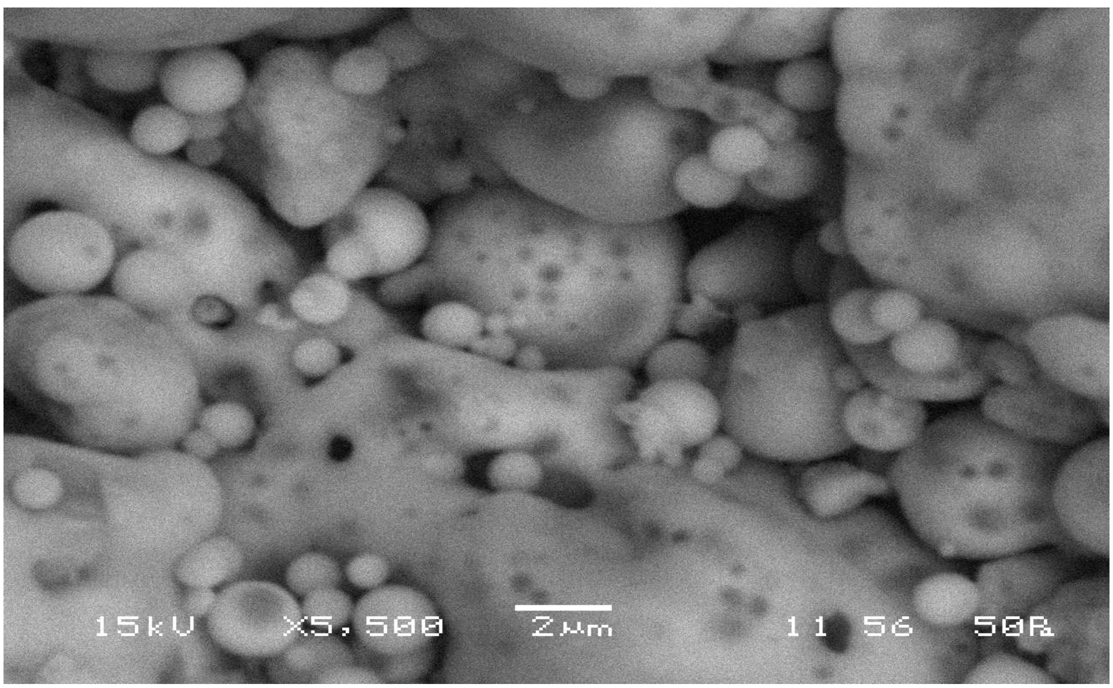


Fig. 3.7.2: Particle Arrangement (SEM) Photograph: Pond Ash

Chapter 4

CHARACTERIZATION OF RED MUD

4.1 In situ Density

The in situ density of red mud is obtained by core cutter method. The samples are collected in the core cutter mould and brought from the site. The open faces of the mould were sealed with a thin layer of wax to prevent loss of moisture in the transit of the moulds from site to the laboratory. Two core cutter moulds were taken from the site to obtain a concurrent value of the in situ density. The following observations are obtained from the core cutter analysis:

Sample I

Total weight of core cutter and red mud = 3566 gm

Weight of mould = 1836 gm

Diameter of mould = 10.3 cm

Height of mould = 15.5 cm

Hence, in situ wet density of ash = (3566 - 1836)/ (π x 10.3^2 x 15.5/4)

= 1.34 gm/cc

In situ moisture content = 33.7%

Sample II

Total weight of core cutter and ash = 3479.6 gm

Weight of mould = 1816 gm

Diameter of mould = 10.4 cm

Height of mould = 15.3 cm

Hence, in situ wet density of ash = (3479.6 - 1816)/ (π x 10.4^2 x 15.3/4)

= 1.28 gm/cc

In situ moisture content = 28.3%

4.2 Standard Proctor Test

Standard proctor test are conducted on red mud sample to obtain the maximum dry density (MDD) and the corresponding optimum moisture content (OMC). The test is conducted on oven dried red mud samples. The volume of the mould used is 1000 cc.

The plot of dry density against the moisture content is as follows:

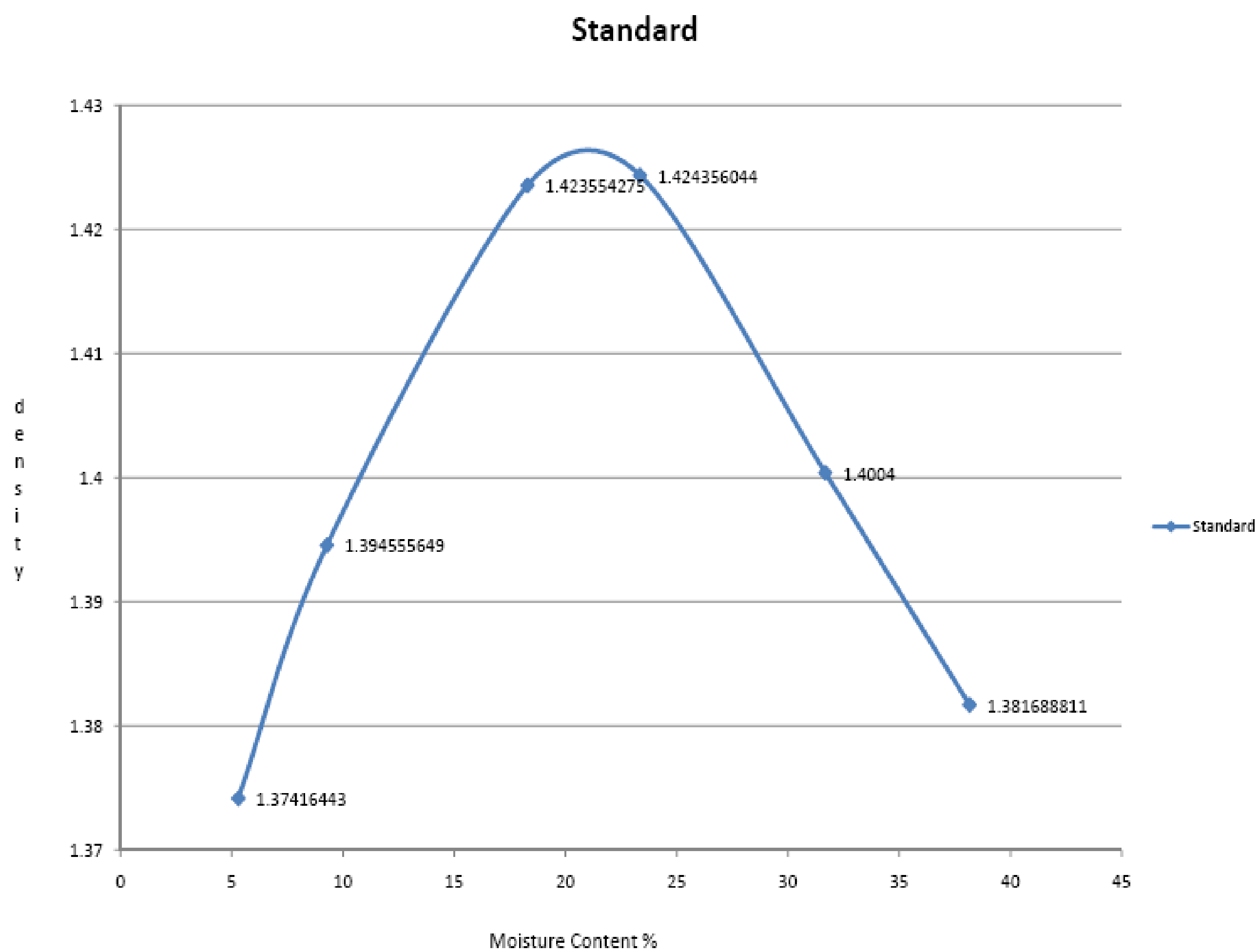


Fig. 4.2.1 Standard Proctor Test: Red Mud

From the above plot, the maximum dry density (MDD) is found to be 1.42 gm/cc and the optimum moisture content (OMC) required to obtain the same is 21%.

4.3 Direct Shear Box test

To obtain the shear strength characteristic of the red mud specimen, direct shear tests were conducted on the red mud samples. The test specimen is prepared by calculating the volume of the shear box and hence finding the mass of dry specimen required for test using the maximum dry density (MDD) obtained from standard Proctor test. The water content is kept equal to the optimum moisture content (OMC), also obtained from standard proctor test.

Dimension of Shear Box: 6 cm x 6 cm x 2.2 cm

The failure envelope is obtained for three normal loads of 5 lb. 10 lb and 15 lb.

The observations for the direct shear test for ash is as follows:

Table 4.3.1 Direct Shear Test: Red Mud

Direct shear test
Sample : Red Mud
OMC = 21%
MDD = 1.42 g/cc

Mass of red mud = 1.42 x 79.2
= 112.464 gm
Water content = 23.6 ml

Normal load(lb)	Normal load(N)	Proving Ring reading	Shear load(N)
5	111.13	30	113.05
10	222.26	51	192.2
15	333.39	76	286.4

The plot of the failure envelope on the basis of the above observations is as follows:

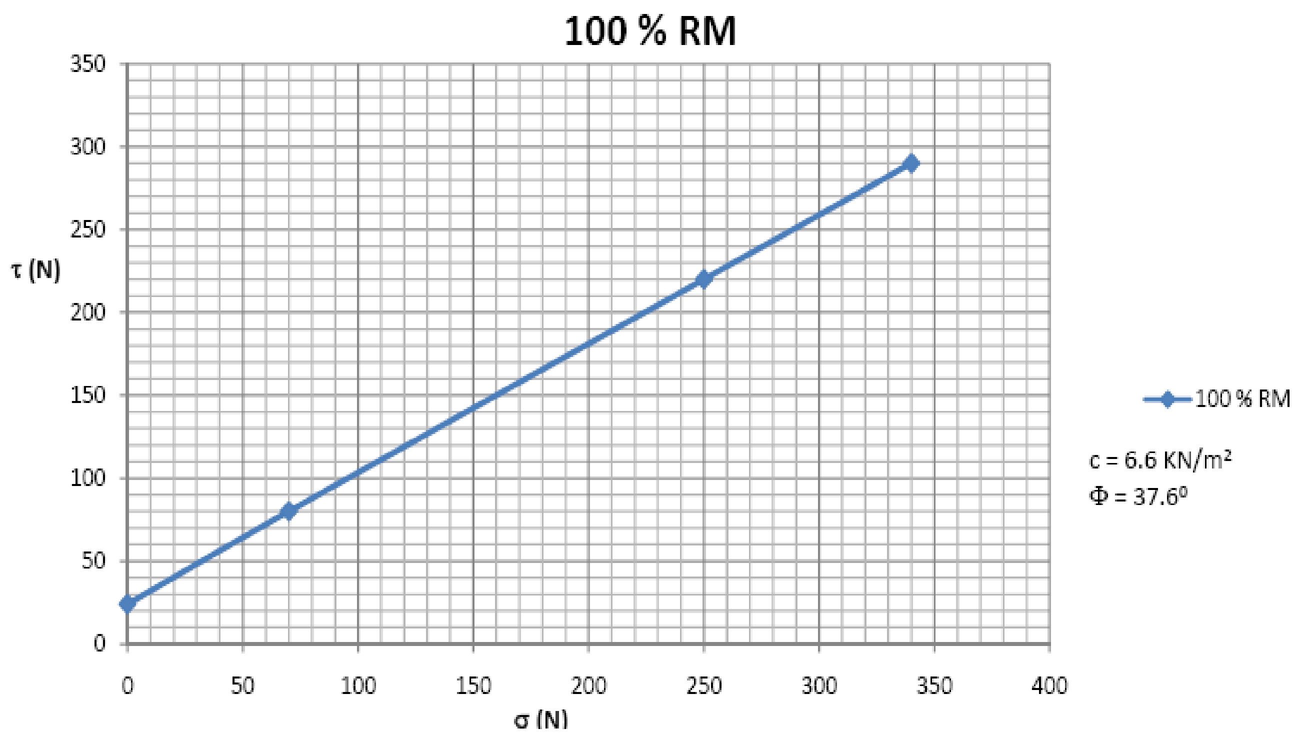


Fig. 4.3.1 Direct Shear Test: Red Mud

From the failure envelope obtained above, the shear strength parameters of red mud are:

c = 6.6 KN/m^2;

Φ = 37.6^0

4.4 Triaxial test

To obtain the shear parameters under 3-d loading conditions, triaxial test is conducted on the red mud. To conduct triaxial test, cylindrical samples are made and put in the triaxial chamber. The dimension of the sample is as follows:

Diameter of specimen = 5.1 cm

Height of specimen = 9.4 cm

The triaxial test is conducted under unconsolidatated undrained condition. To obtain the above drainage condition, the sample is covered by membrane and impervious Perspex discs are placed on both the open ends and tied to the membrane tightly using rubber bands.

The triaxial tests are conducted under cell pressures of 0.6 Pa, 0.8 Pa and 1.0 Pa to obtain three sets of Mohr's circle of stresses and hence plot the failure envelope.

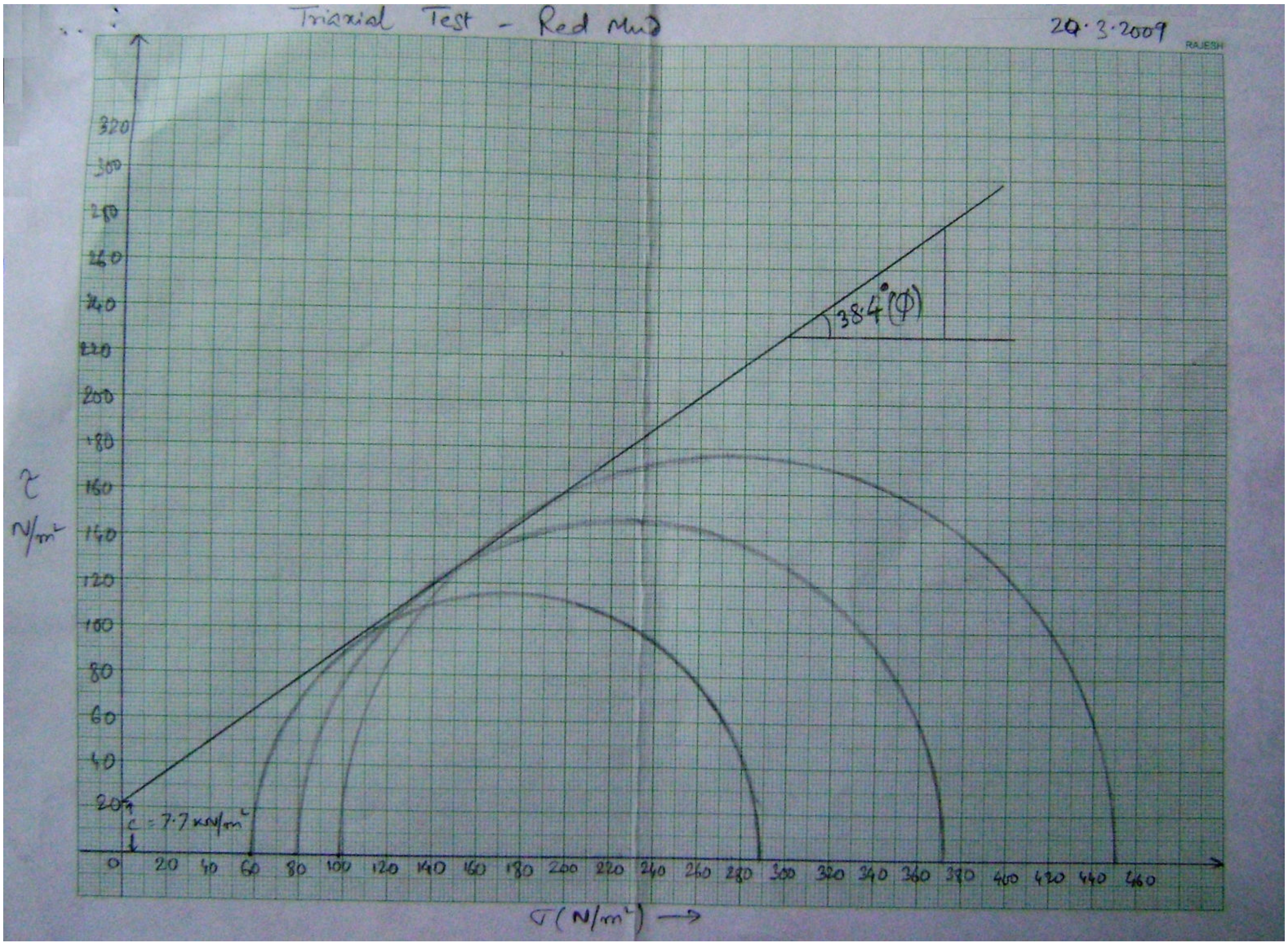


Fig. 4.4.1 Triaxial Shear Test: Red Mud

From the failure envelope, the shear strength parameters of red mud under triaxial loading conditions are:

c = 7.7 KN/m^2

Φ = 38.4^0

4.5 Permeability Test

4.5.1 Constant Head Permeability Test

The coefficient of permeability of the red mud is found out by constant head permeameter. The observation of the constant head permeameter test is as follows:

Diameter of mould, d = 11 cm

Height of mould, h = 13.8 cm

Volume of mould = 1311.45 cc

Weight of red mud required = 1311.45 x 1.42

= 1862.26 gm

The sample of red mud filled in the mould is allowed to saturate fully before performing the test.

Table 4.5.1 Constant Head Permeability: Red Mud

H (cm)	L (cm)	Hydraulic gradient, *i*	A (cm^2)	Vol. of water (ml)	Time taken to collect water, t (sec)	Coefficient of permeability, κ (cm/s)
13.8	1.0	0.081	95.03	5	910	6.023e-7
13.8	1.8	0.081	95.03	5	720	6.37e-7

Thus the average coefficient of permeability of red mud under constant head permeability is found out to be 6.19e-7 cm/s.

4.4.2 Falling Head Permeability test

The coefficient of permeability of the red mud specimen is also found out using falling head permeameter. The observations for falling head permeameter test are as follows:

Diameter of mould, d = 11 cm

Height of mould, h = 13.8 cm

Volume = 1311.45 cc

Weight of red mud required = 1311.45 x 1.42

= 1862.26 gm

Table 4.5.2 Falling Head Permeability: Red Mud

Initial head, h1(cm)	Final head, h2(cm)	Volume of water, V (ml)	Time taken to collect, t (sec)	Area of cross-section, A (cm2)	a (cm2)	Coefficient of permeability, κ (cm/s)
80.5	40.5	20	356	95.03	1.88e-3	6.29e-7
100	60	18	283	95.03	2.4e-3	6.7e-7

Thus the coefficient of permeability of red mud is found out to be 6.495e-7 cm/s.

4.6 Specific Gravity test

The specific gravity of red mud is obtained as 3.41

4.7 Mineralogy test

The mineralogy analysis and the particle arrangement of oven dried red mud samples are carried out under (SEM). The constituent of various minerals in % by weight is as follows:

Table 4.7.1 Mineralogy: Red Mud

Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
C K	39.86	0.7896	34.66	1.06	47.11
O K	49.81	0.8485	40.30	1.08	41.12
Na K	6.40	0.9790	4.49	0.28	3.19
Al K	6.60	0.8947	5.07	0.25	3.07
Si K	3.37	0.9082	2.54	0.20	1.48
Ti K	6.29	0.8179	5.28	0.36	1.80
Fe K	8.79	0.7885	7.66	0.57	2.24
Totals			100.00		

The proportion of different constituent minerals is graphically plotted as follows:

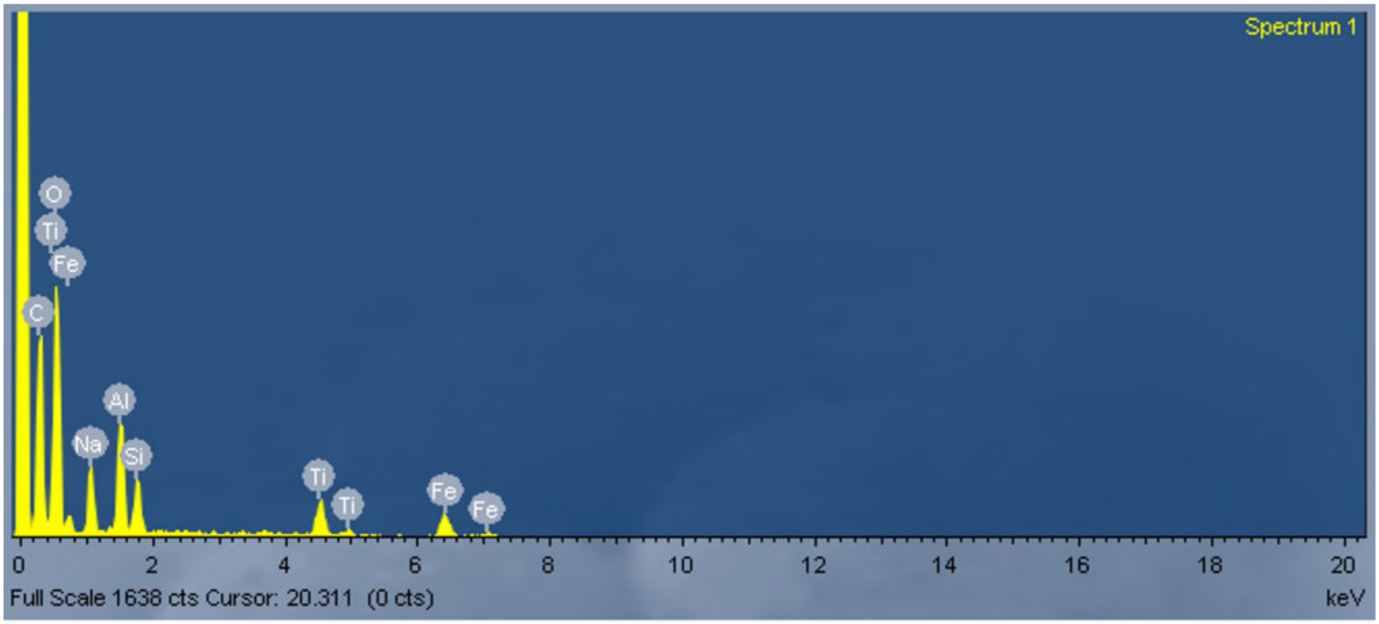


Fig. 4.7.1 Mineralogy Analysis: Red Mud

The arrangement of particles in the specimen is viewed at a magnification of 5500 at 15 kV under the scanning electron microscope in a pressure of 50 pa. The photograph of the magnified view is as follows:

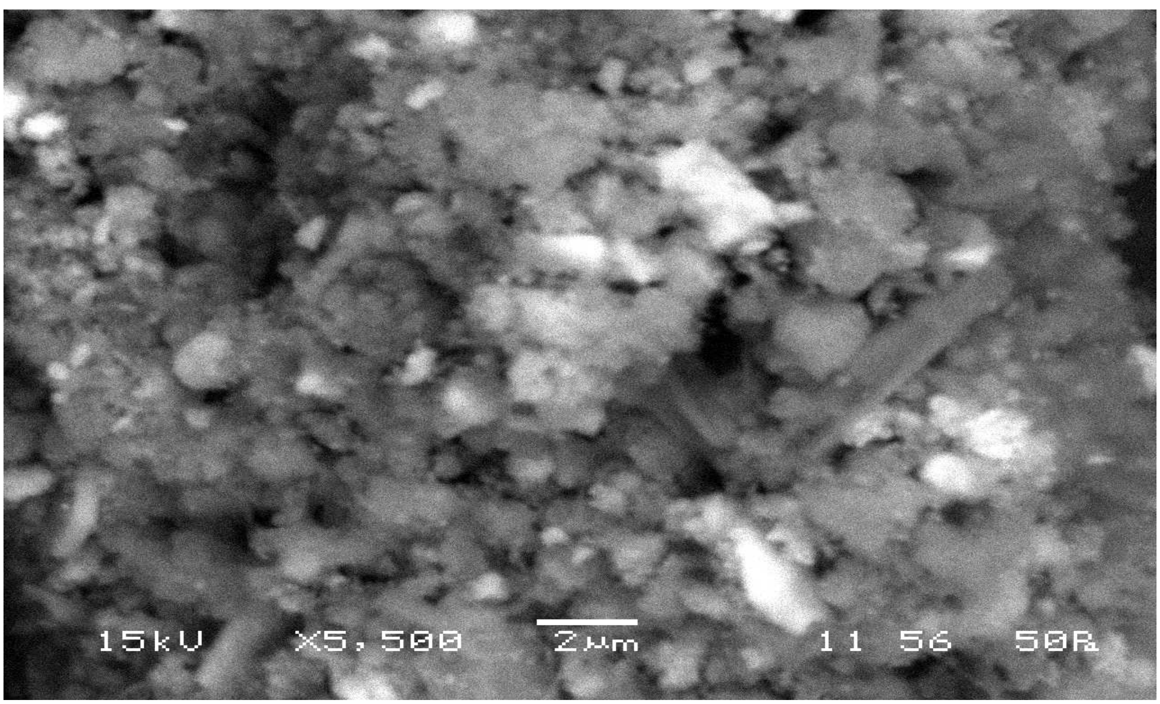


Fig. 4.7.2 Particle Arrangement (SEM Photograph): Red Mud

Chapter 5

DETERMINATION OF OPTIMUM MIX

The ash and red mud specimens are mixed in various proportions to determine a particular mix at which the geotechnical characteristics are most favorable for construction of embankments. The red mud and ash samples are mixed in the following proportions:

i. 90% red mud + 10% ash
ii. 80% red mud + 20% ash
iii. 70% red mud + 30% ash
iv. 60% red mud + 40% ash
v. 50% red mud + 50% ash

All the above mixes are analyzed for their maximum dry density (MDD) and corresponding optimum moisture content by standard proctor test. The specific gravity of each mixture is also determined to account for the fineness o the particles in the mixtures. After determination of MDD and OMC, the mixtures are analyzed for their shear strength and cohesive strength under 2-d and 3-d failure conditions using direct shear box test and triaxial test.

To account for the arrangement of the particles and the mineralogical characteristics of the mixtures, samples from each mixture is observed under (scanning electron microscope) SEM.

5.1 Standard Proctor Test of Mix Proportions

The plots of the dry density against moisture content for various mixtures of ash and red mud are as follows:

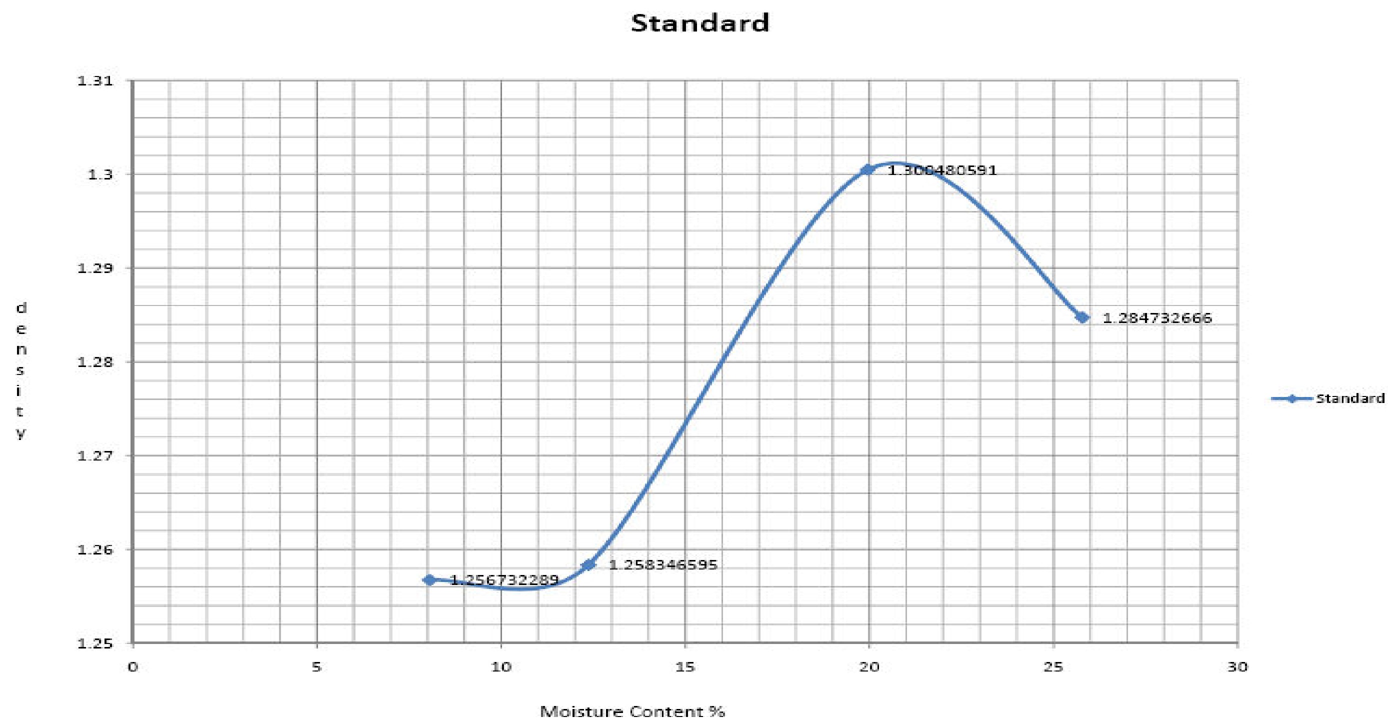


Fig 5.1.1 Standard Proctor Test: 50% Red Mud + 50% Ash

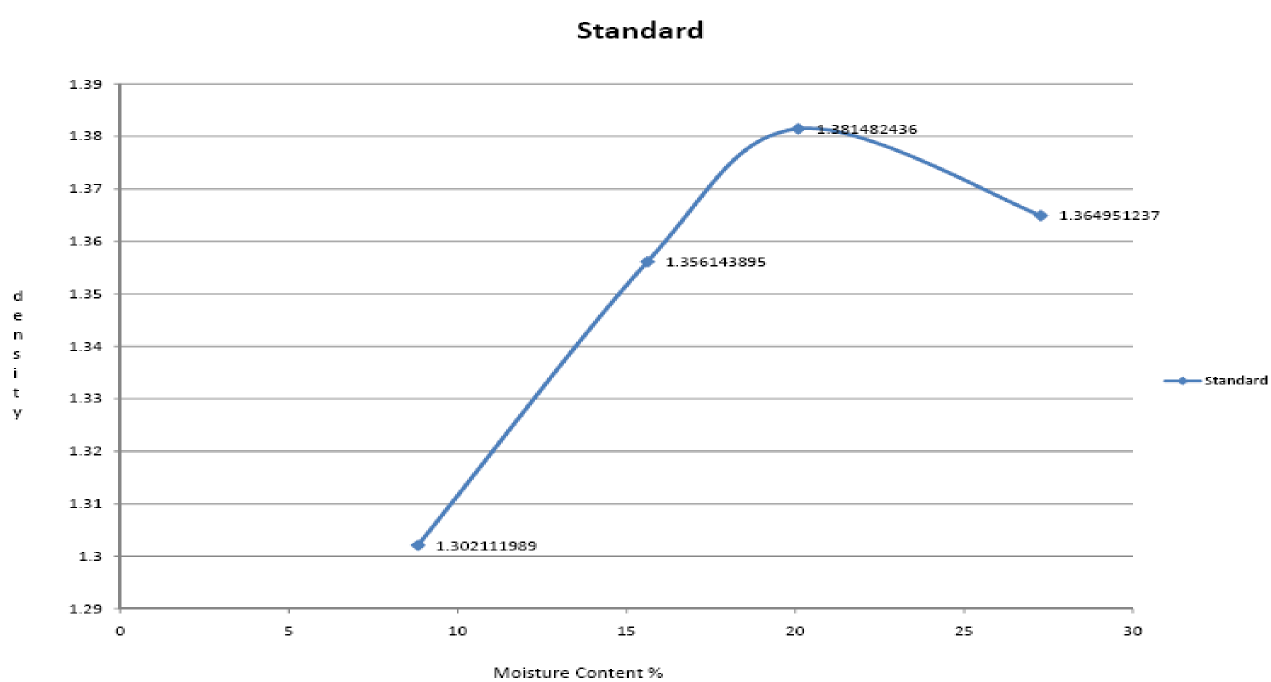


Fig 5.1.2 Standard Proctor Test: 60% Red Mud +40% Ash

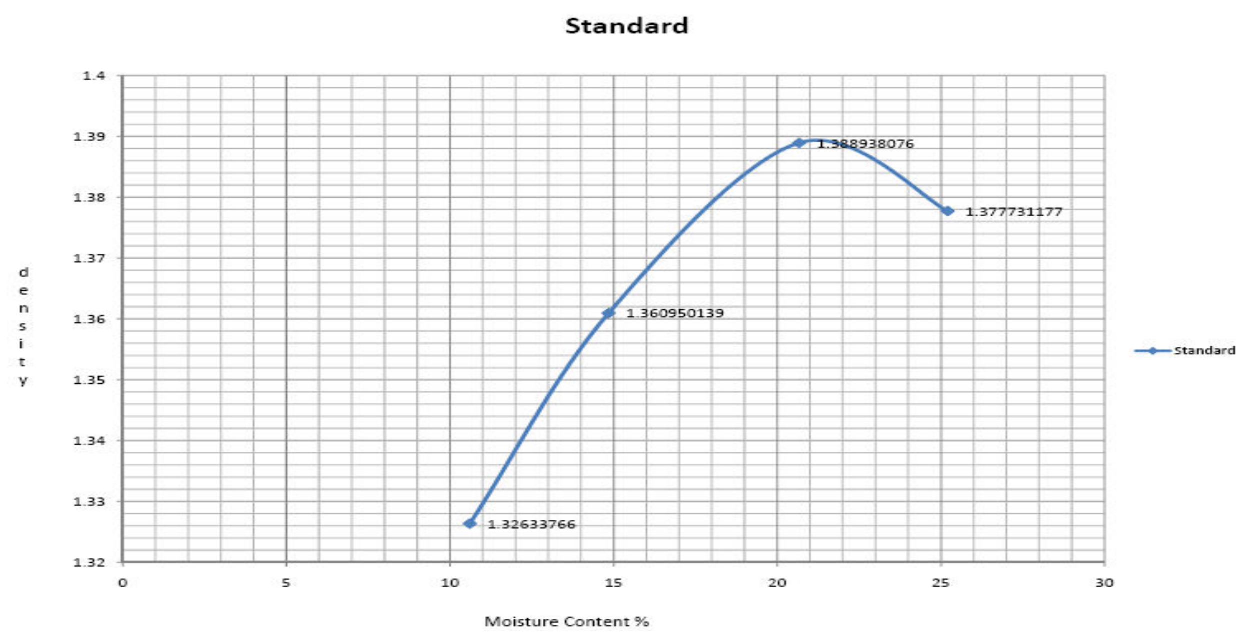


Fig 5.1.3 Standard Proctor Test: 70% Red Mud +30% Ash

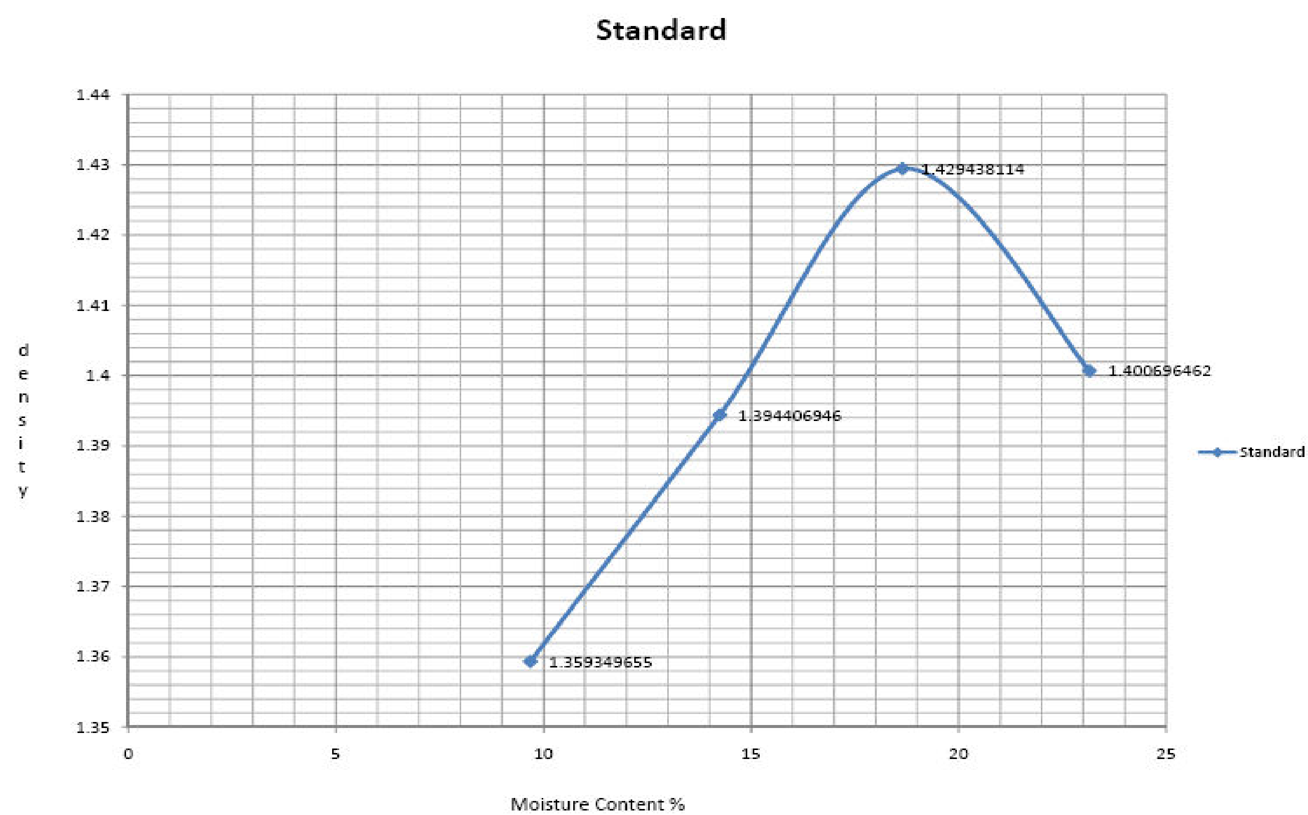


Fig 5.1.4 Standard Proctor Test: 80% Red Mud +20% Ash

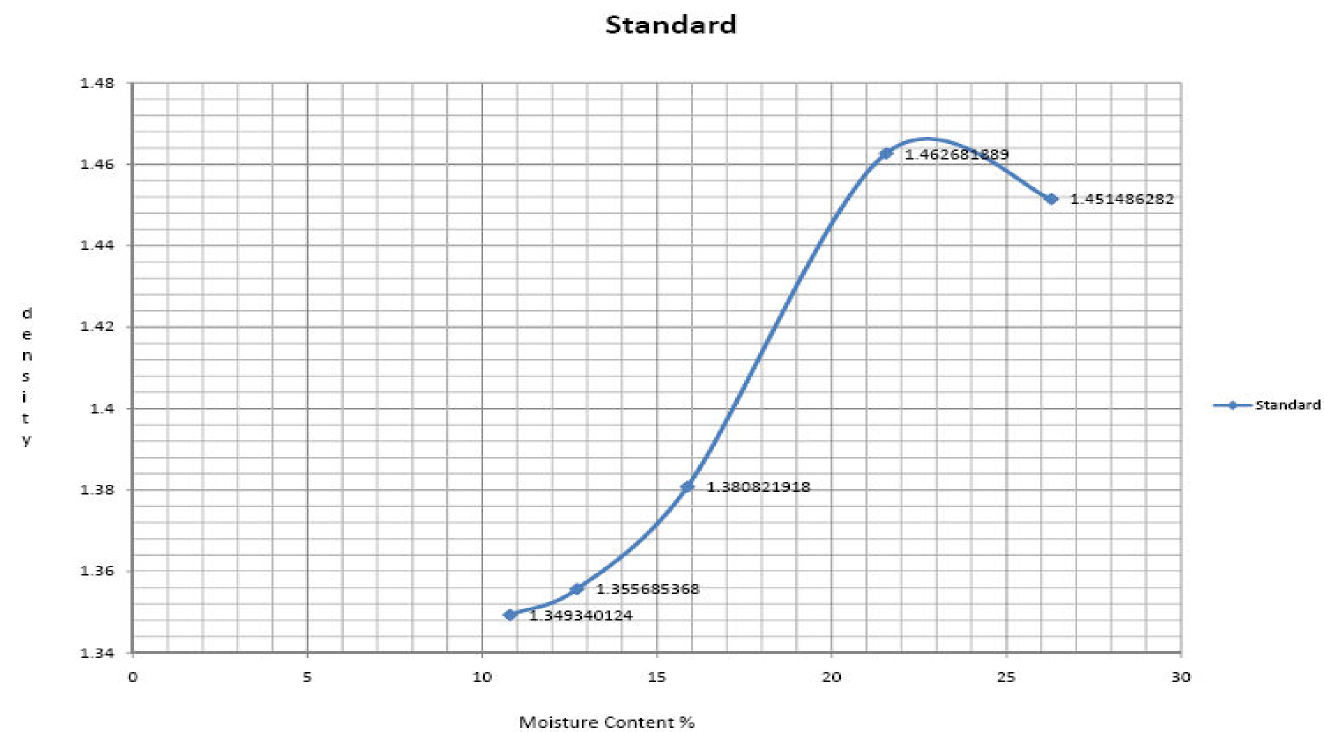


Fig 5.1.5 Standard Proctor Test: 90% Red Mud +10% Ash

The maximum dry density for red mud is found out to be 1.42 gm/cc. From the above plots of dry density and moisture content of various mixtures, the maximum dry density is found out to be 1.46 gm/cc, possessed by the mixture containing 90% red mud and 10% ash. The corresponding optimum moisture content is 22%.

5.2 Direct Shear Box Test of Mix Proportions

The experimental observations for dire4ct shear box tests of various mixtures and the corresponding plots to obtain shear strength parameters, c and Φ, is as follows:

Table 5.2.1 Direct Shear Test: 50% Red Mud + 50% Pond Ash

Direct shear test
Sample : 50%Red Mud and 50% Pond ash
OMC = 20.5%
MDD = 1.305 g/cc

For 120 gms,
Mass of red mud = 60 gm
Mass of ash = 60 gm
Water = 24.6 ml
Mass of mixture required = 1.305 x 79.2
= 103.36 gm

Normal load(lb)	Normal load(N)	Proving Ring reading	Shear load(N)
5	111.13	29	109.1
10	222.26	47	180.06
15	333.39	66	251.2

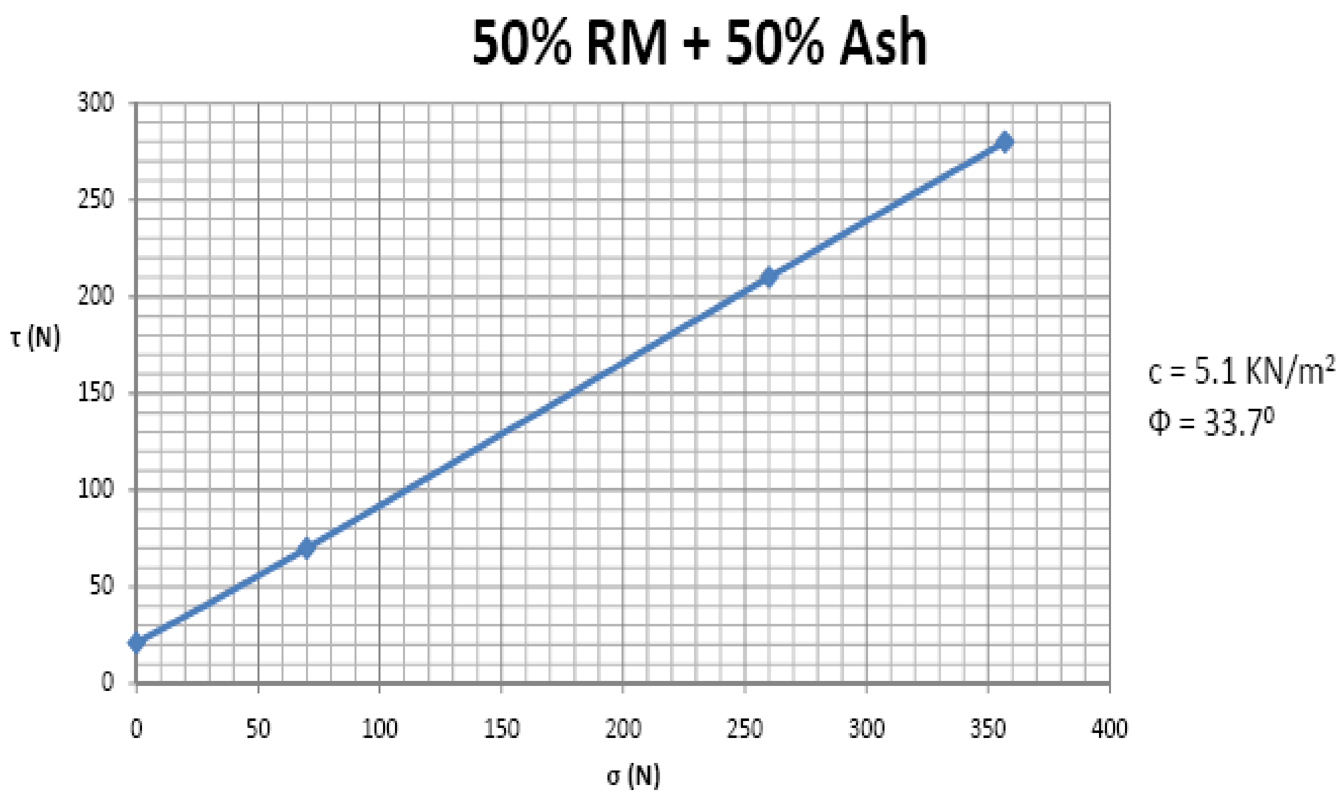


Fig. 5.2.1 Direct Shear Test: 50% Red Mud + 50% Pond Ash

Table 5.2.2 Direct Shear Test: 60% Red Mud + 40% Pond Ash

Direct shear test
Sample : 60%Red Mud and 40% Pond ash
OMC = 20%
MDD = 1.38 g/cc

For 120 gms,
Mass of red mud = 72 gm
Mass of ash = 48 gm
Water = 24 ml
Mass of mixture required = 1.38 x 79.2
= 109.3 gm

Normal load(lb)	Normal load(N)	Proving Ring reading	Shear load(N)
5	111.13	27	102.8
10	222.26	47	180.16
15	333.39	67	256.2

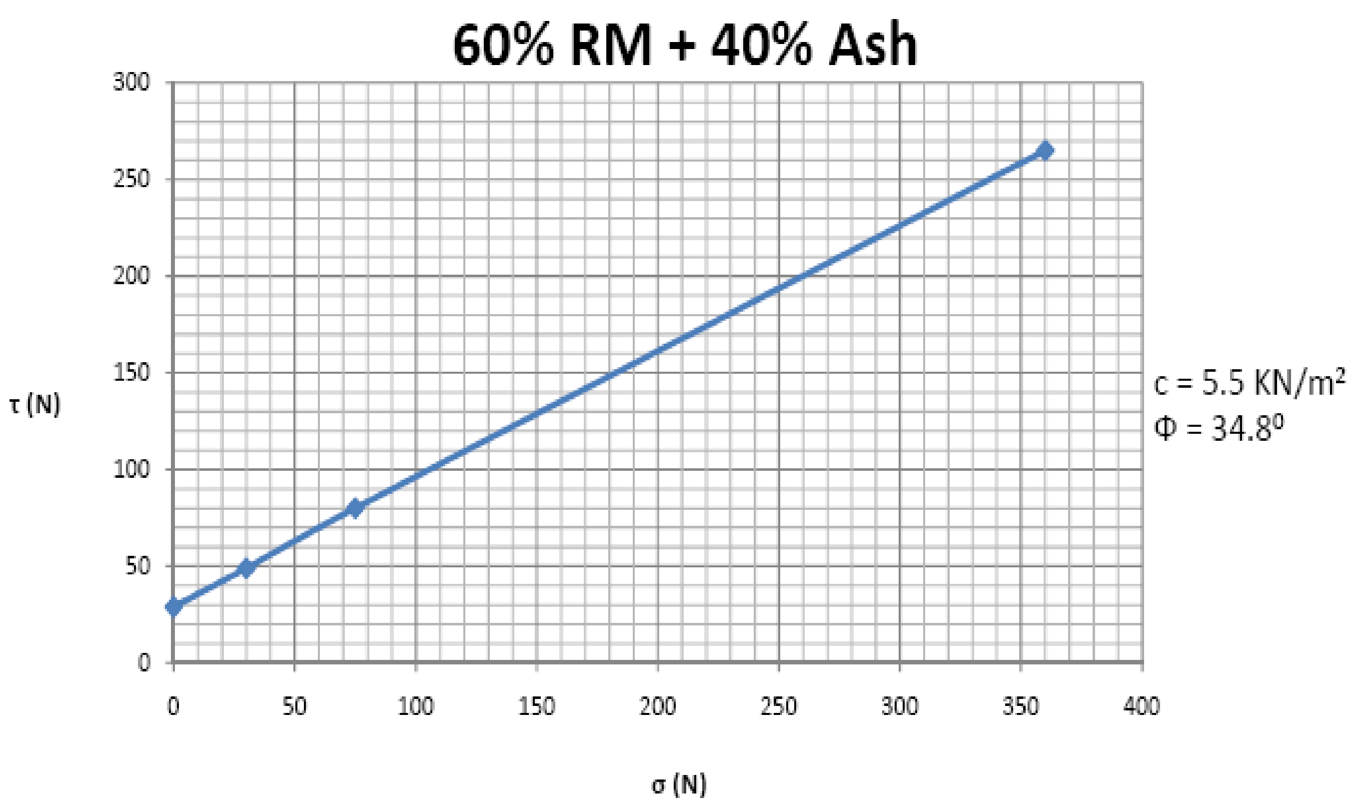


Fig. 5.2.2 Direct Shear Test: 60% Red Mud + 40% Pond Ash

Table 5.2.3 Direct Shear Test: 70% Red Mud + 30% Pond Ash

Direct shear test
Sample : 70%Red Mud and 30% Pond ash
OMC = 21%
MDD = 1.39 g/cc

For 120 gms,
Mass of red mud = 84 gm
Mass of ash = 36 gm
Water = 25.2 ml
Mass of mixture required = 1.39 x 79.2
= 110.09 gm

Normal load(lb)	Normal load(N)	Proving Ring reading	Shear load(N)
5	111.13	27	102.8
10	222.26	48	182.6
15	333.39	69	263.4

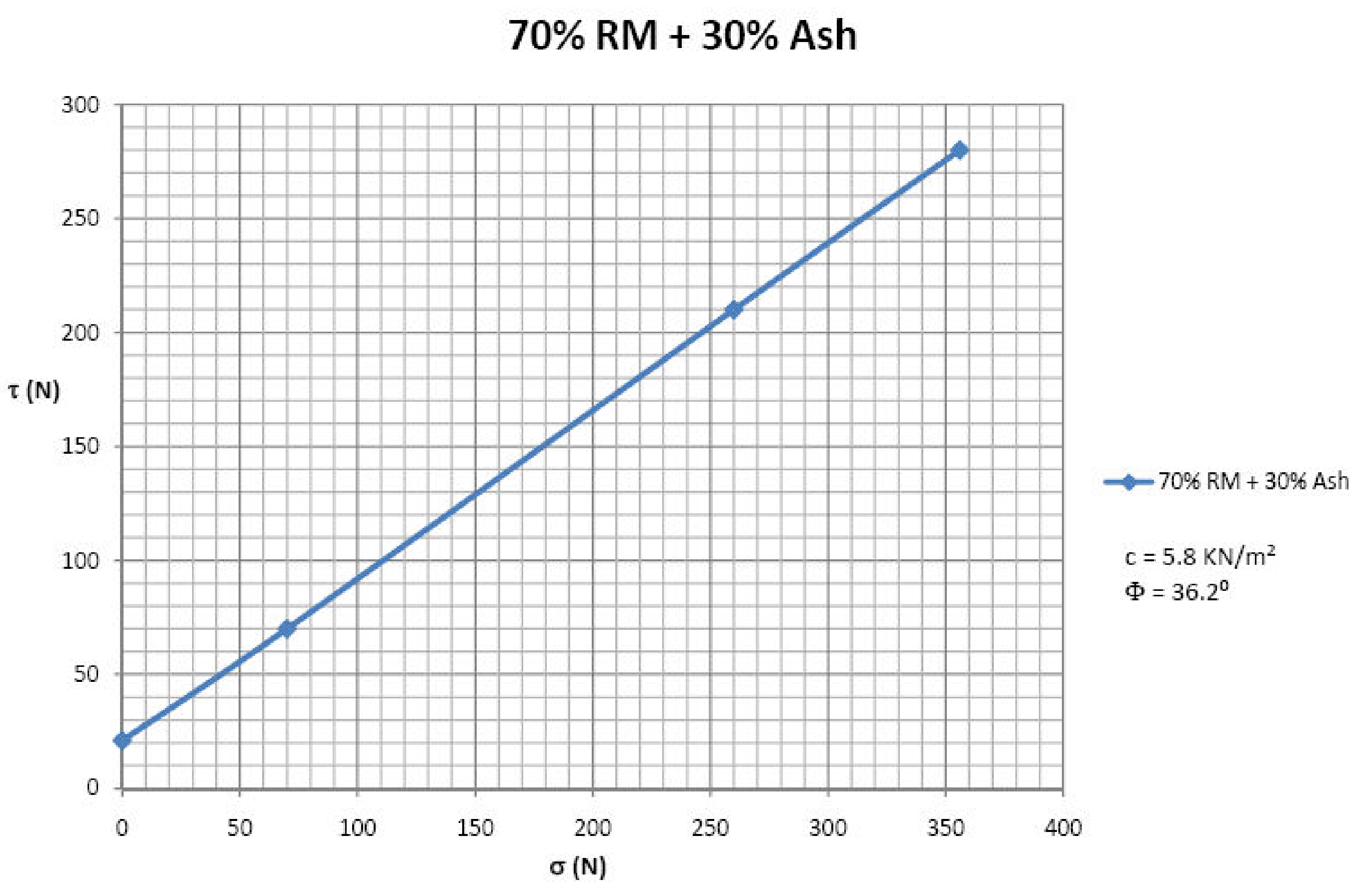


Fig. 5.2.3 Direct Shear Test: 70% Red Mud + 30% Pond Ash

Table 5.2.4 Direct Shear Test: 80% Red Mud + 20% Pond Ash

Direct shear test
Sample : 80%Red Mud and 20% Pond ash
OMC = 19%
MDD = 1.43 g/cc

Mass of red mud used = 0.8 x 1.43 x 79.2
= 90.60 gm
Mass of ash used = 22.65 gm
Water content = 0.19 x 113.6
= 21.59 ml

Normal load(lb)	Normal load(N)	Proving Ring reading	Shear load(N)
5	111.13	28	105.1
10	222.26	48	182.2
15	333.39	73	279.84

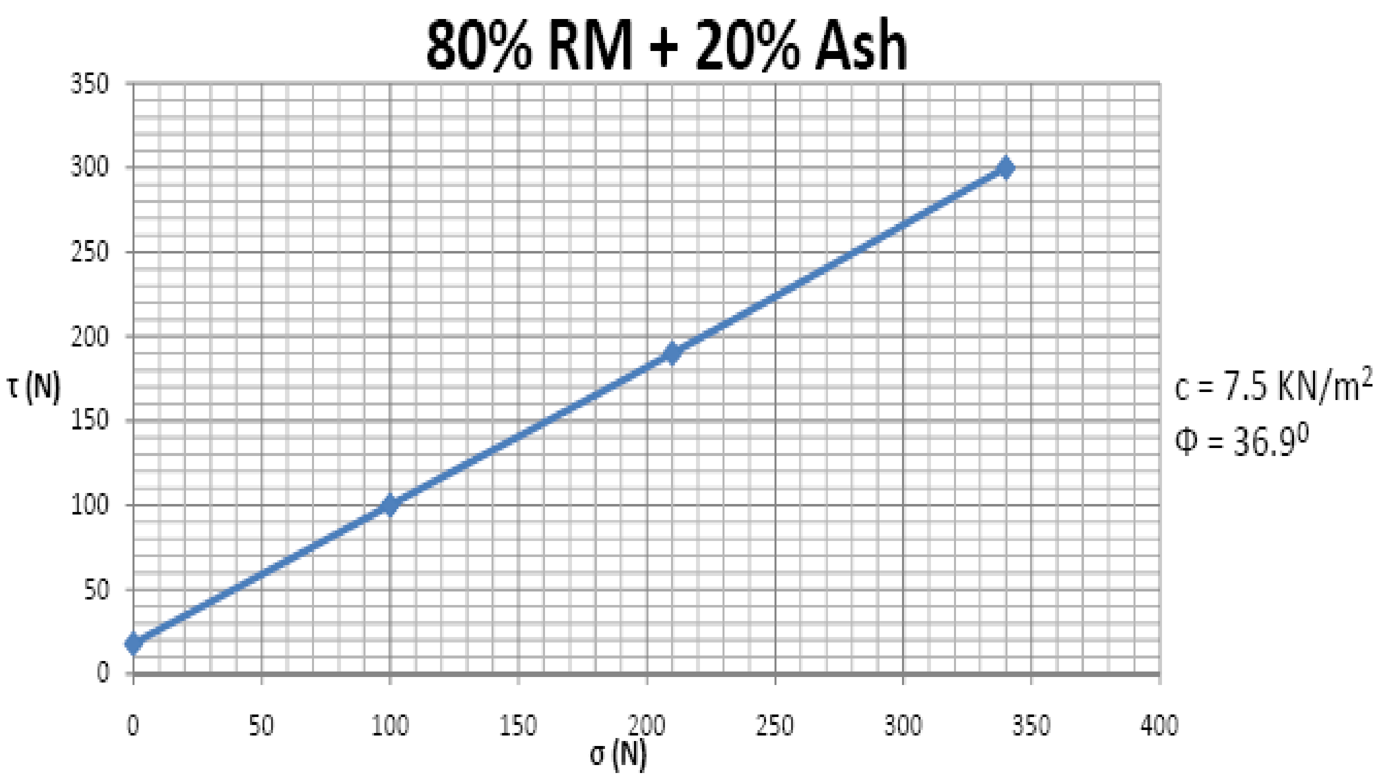


Fig. 5.2.4 Direct Shear Test: 80% Red Mud + 20% Pond Ash

Table 5.2.5 Direct Shear Test: 90% Red Mud + 10% Pond Ash

Direct shear test

Sample : 90%Red Mud and 10% Pond ash

OMC = 22.5%

MDD = 1.464 g/cc

For 120 gms,

Mass of red mud = 108 gm

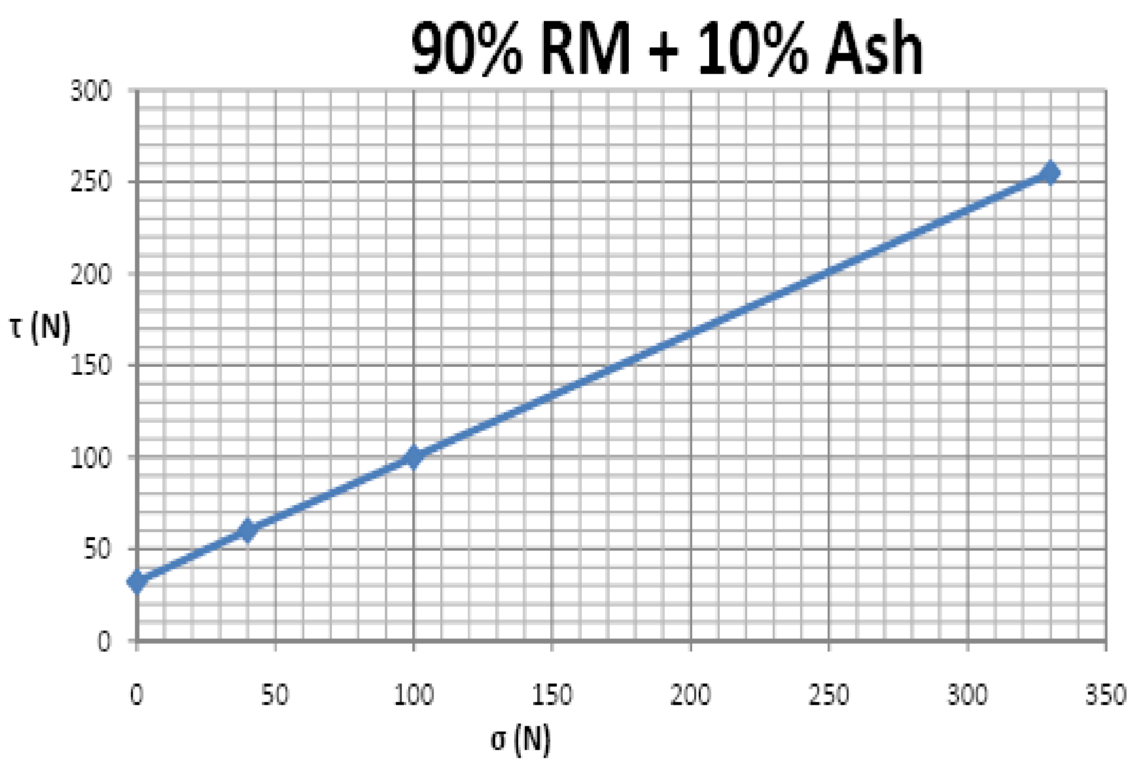
Mass of ash = 12 gm

Water = 27 ml

Mass of mixture required = 1.464 x 79.2

= 115.95 gm

Normal load(lb)	Normal load(N)	Proving Ring reading	Shear load(N)
5	111.13	29	110.1
10	222.26	53	200.6
15	333.39	79	297.7



c = 8.8 KN/m^2

Φ = 38.2^0

Fig. 5.2.5 Direct Shear Test: 90% Red Mud + 10% Pond Ash

From the above plots of various mixes, the value of c is found to be maximum for the mixture having 90% red mud + 10% pond ash for which c = 8.8 KN/m^2 and is decreasing with reducing proportion of red mud in mixtures. The Φ value is found to be progressively increasing from the mixture of 50% red mud + 50% pond ash to that of 90% red mud + 10% pond ash, the maximum value being, $\Phi = 38.2^0$ for the mixture having 90% red mud and 10% pond ash.

5.3 Triaxial Test of Mix Proportions

To obtain the 3-d shear strength parameters, triaxial shear test are conducted on the various mixture samples and compared against the direct shear box test. The experimental observations and the plots of Mohr's stress circle for various mixtures are as follows:

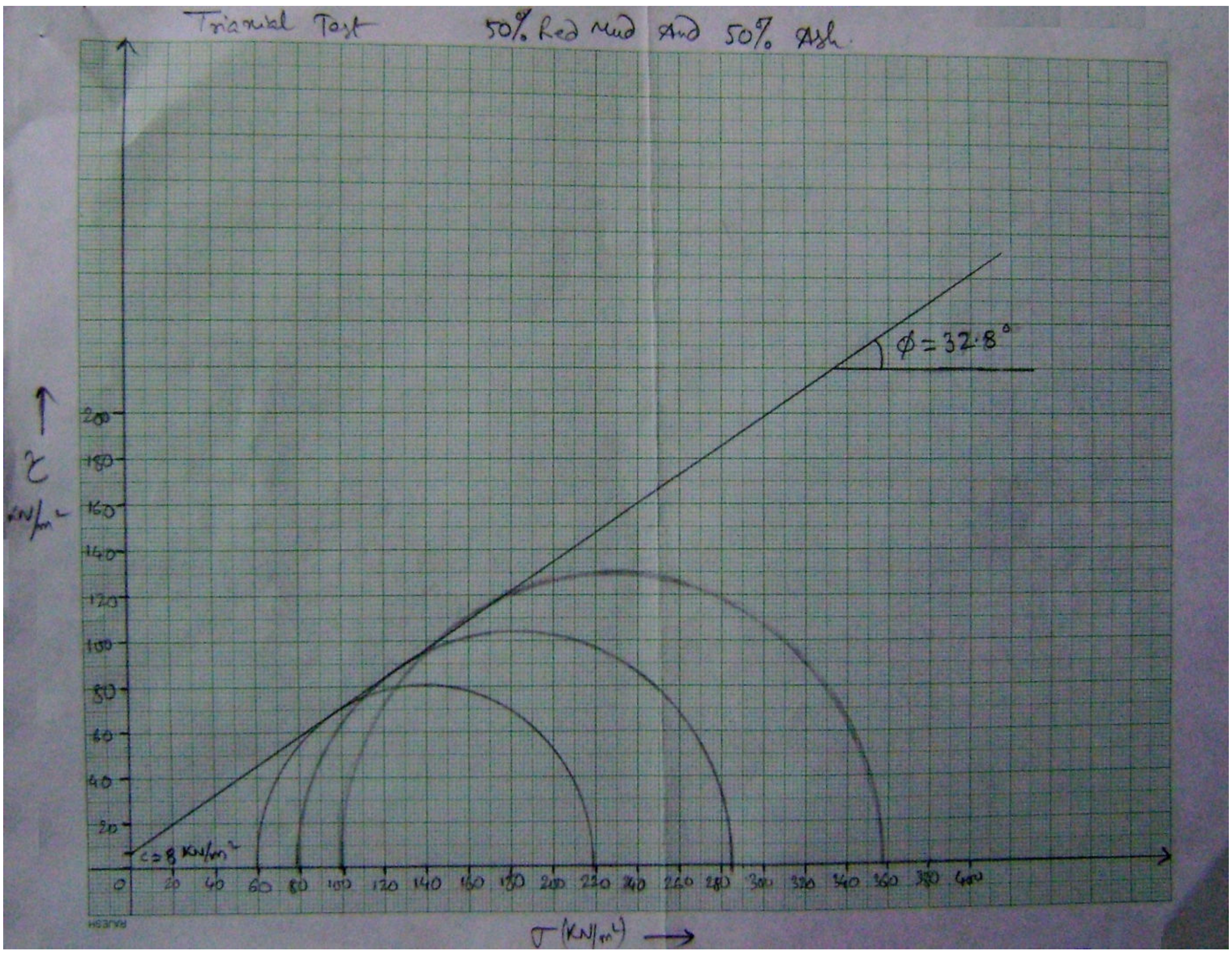


Fig. 5.3.1 Triaxial Test: 50% Red Mud + 50% Ash

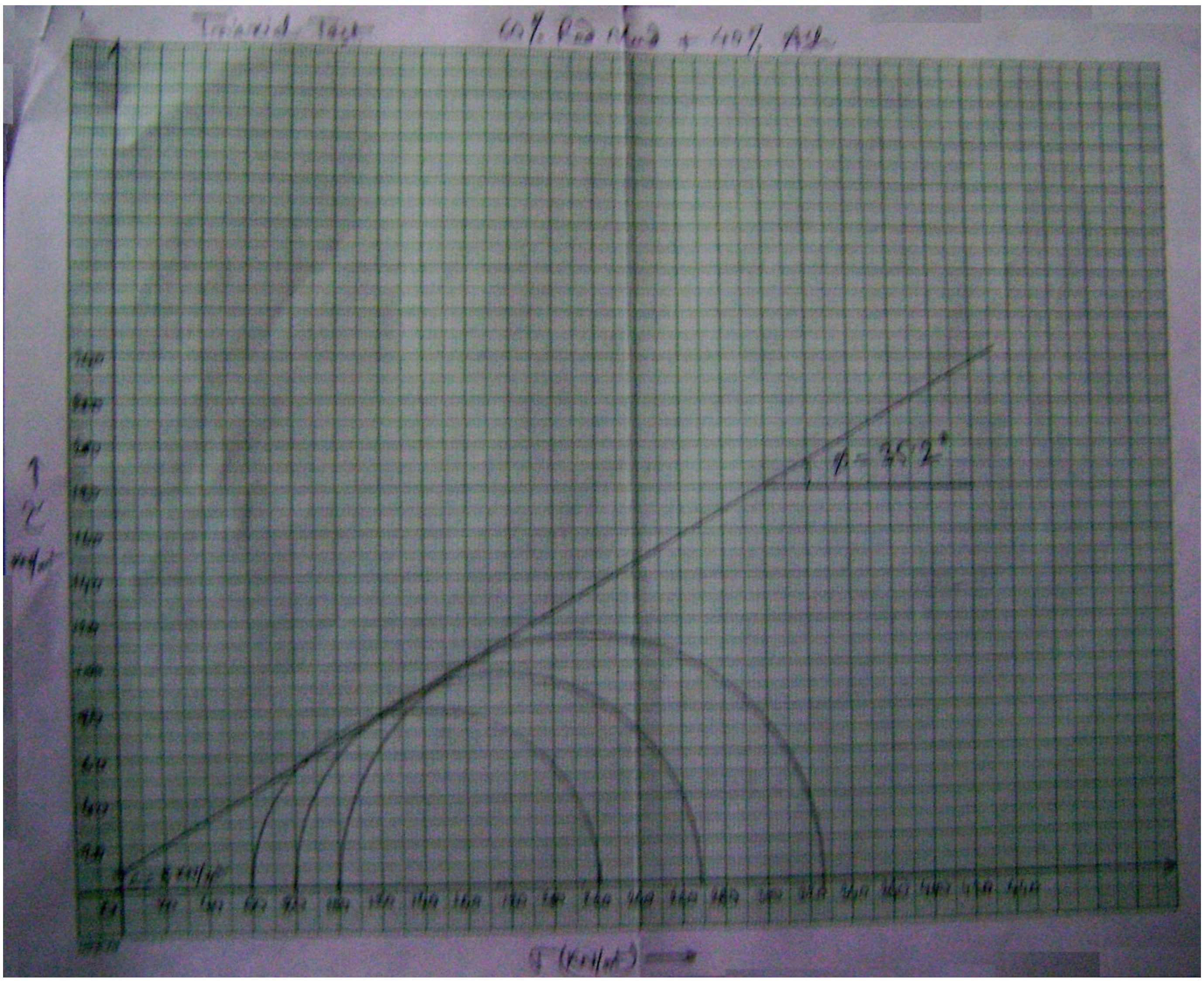


Fig. 5.3.2 Triaxial Test: 60% Red Mud + 40% Ash

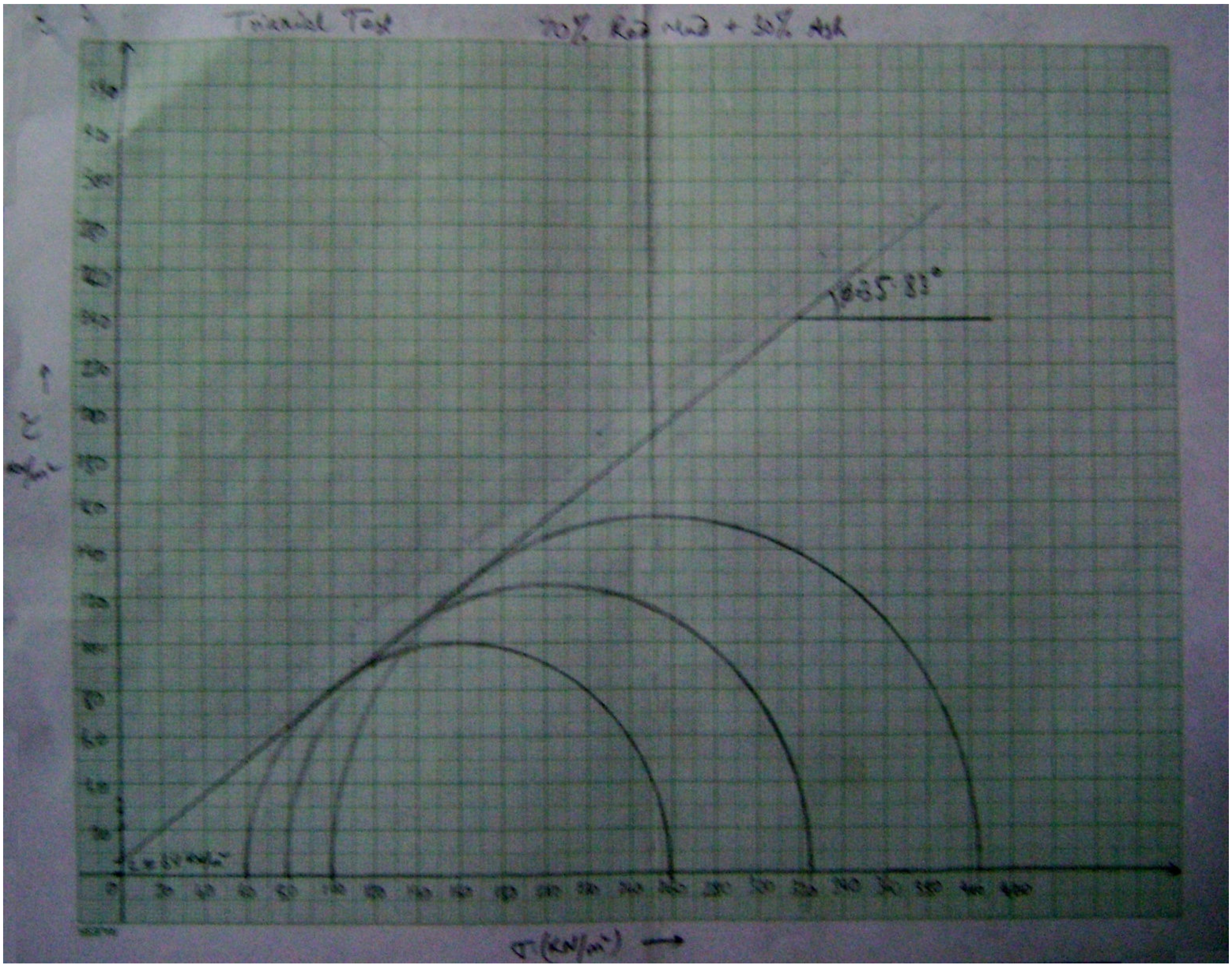


Fig. 5.3.3 Triaxial Test: 70% Red Mud + 30% Ash

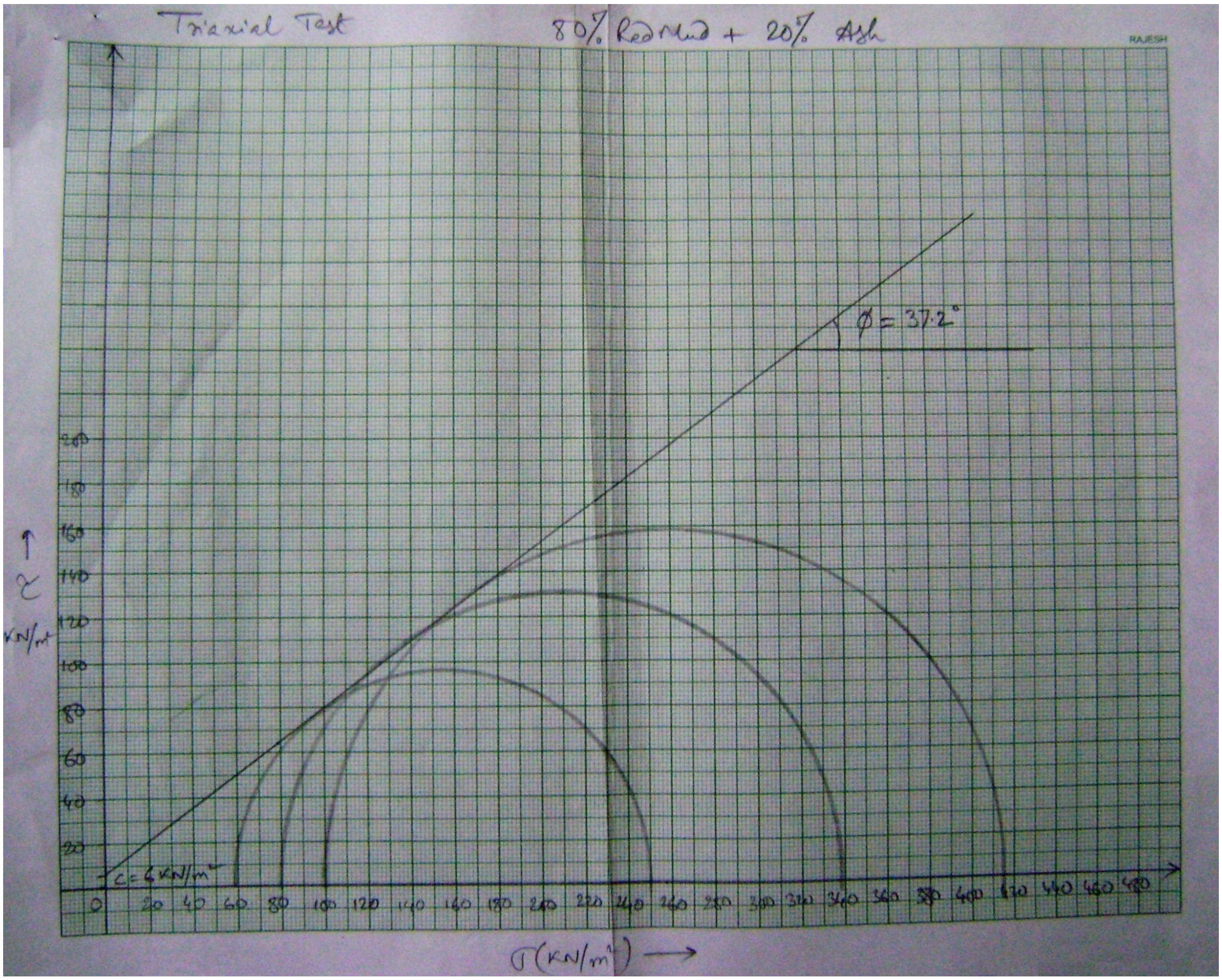


Fig. 5.3.4 Triaxial Test: 80% Red Mud + 20% Ash

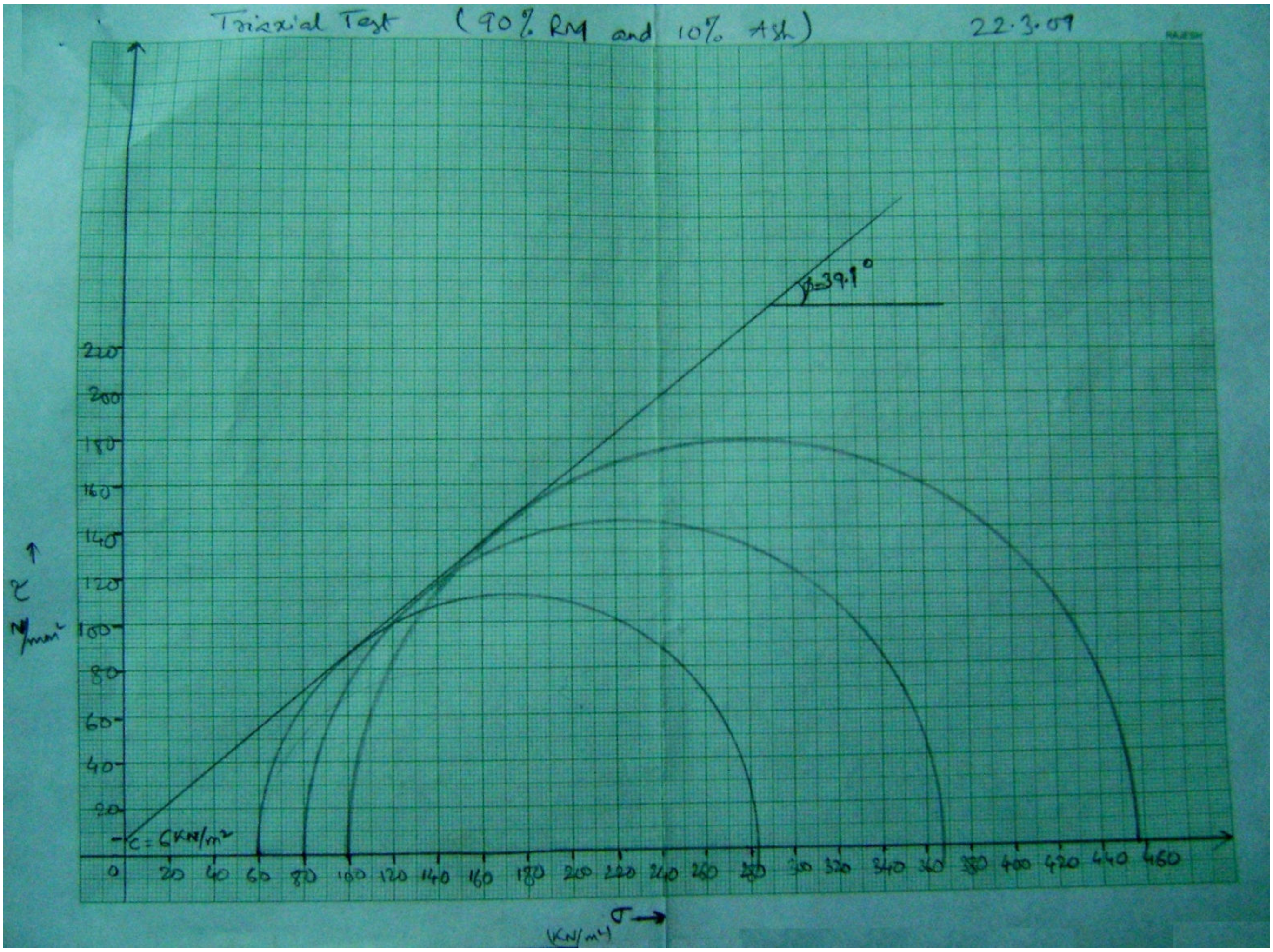


Fig. 5.3.5 Triaxial Test: 90% Red Mud + 10% Ash

From the above plots of Mohr's stress circles, the maximum value of cohesion, c = 8 KN/m^2 for the mixture having a proportion of 90% red mud + 10% ash and the maximum value of Φ = 39.1^0 is also observed for the mixture having proportion of 90% red mud + 10% ash. This result conforms to the obtained from that of direct shear box analysis of the mixtures **(5.2)**.

5.4 Mineralogy Test of Mix Proportions

The various mixtures were observed under scanning electron microscope (SEM) to study the mineral constituents, quantitatively and qualitatively, and also obtain the particle arrangement photograph of each mixture as follows:

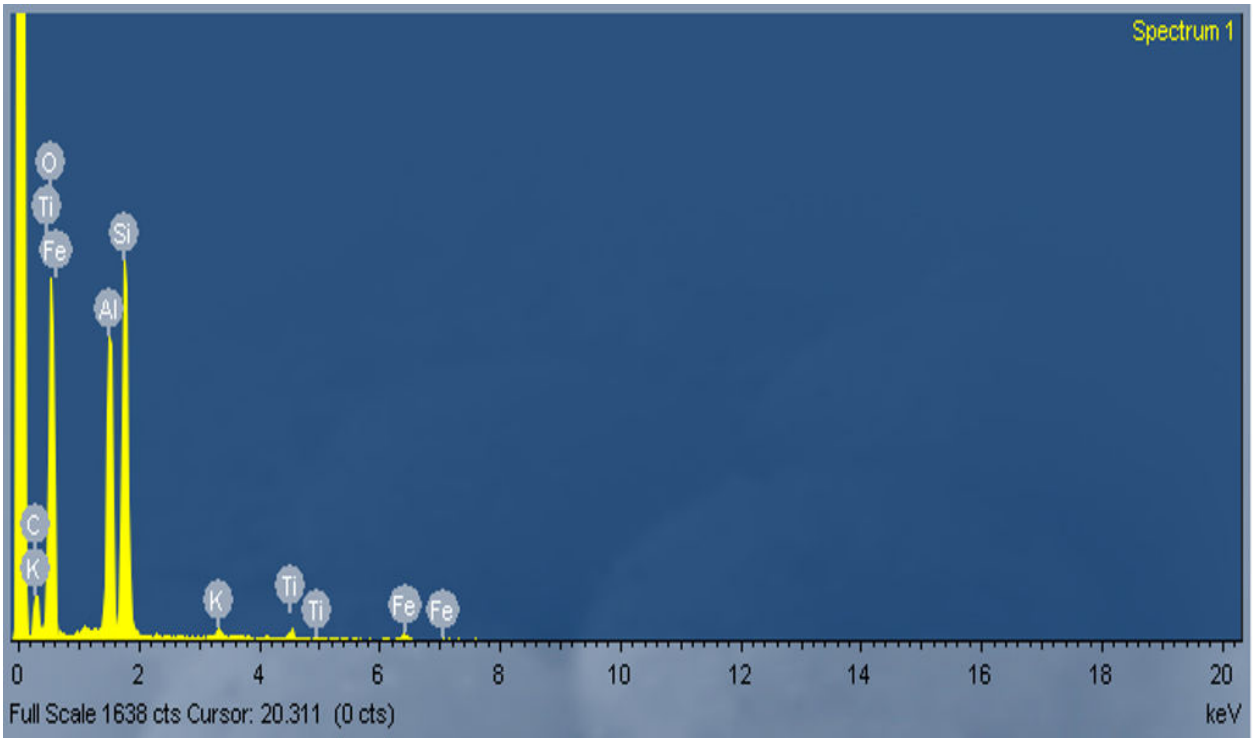


Fig 5.4.1 Mineralogy Analysis: 50% Red Mud + 50% Ash

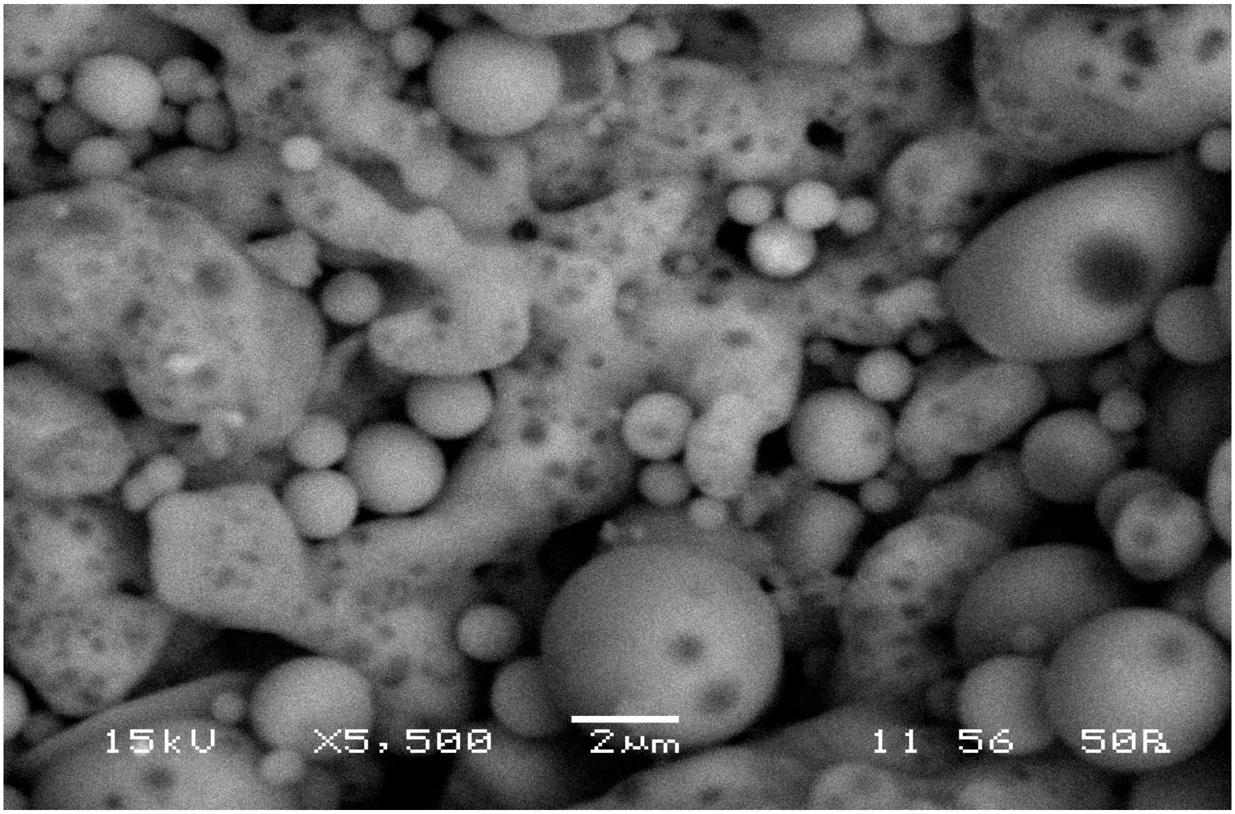


Fig 5.4.2 Particle Arrangement (SEM Photograph): 50% Red Mud + 50% Ash

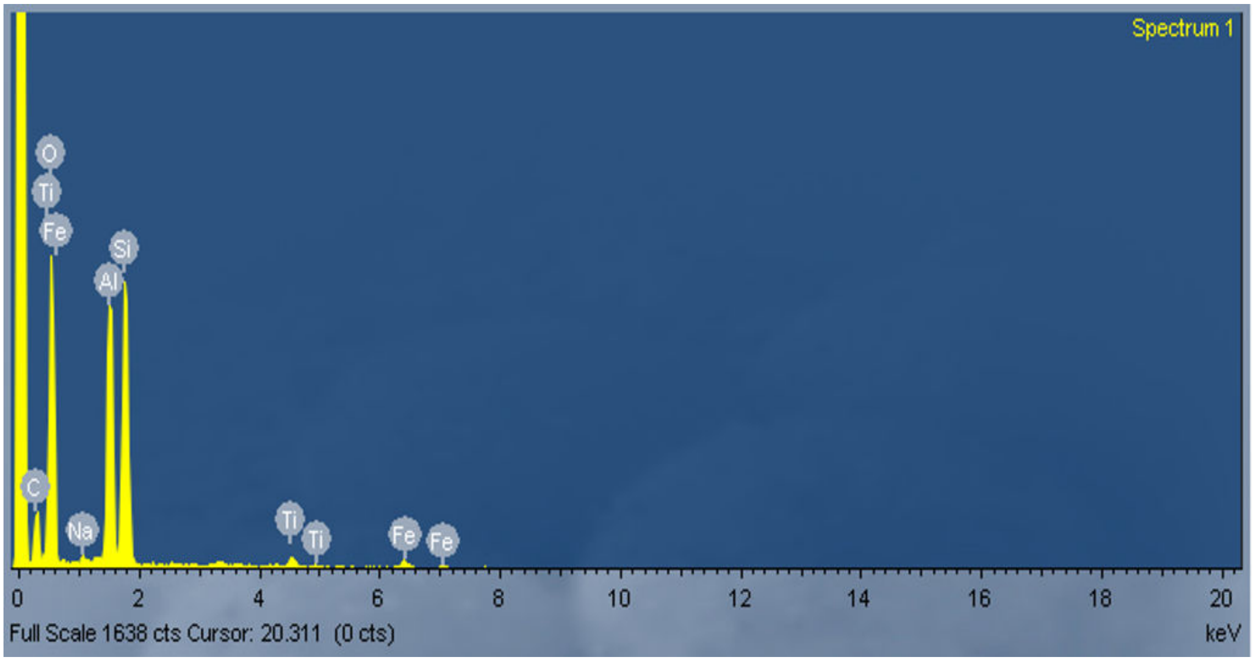


Fig 5.4.3 Mineralogy Analysis: 60% Red Mud + 40% Ash

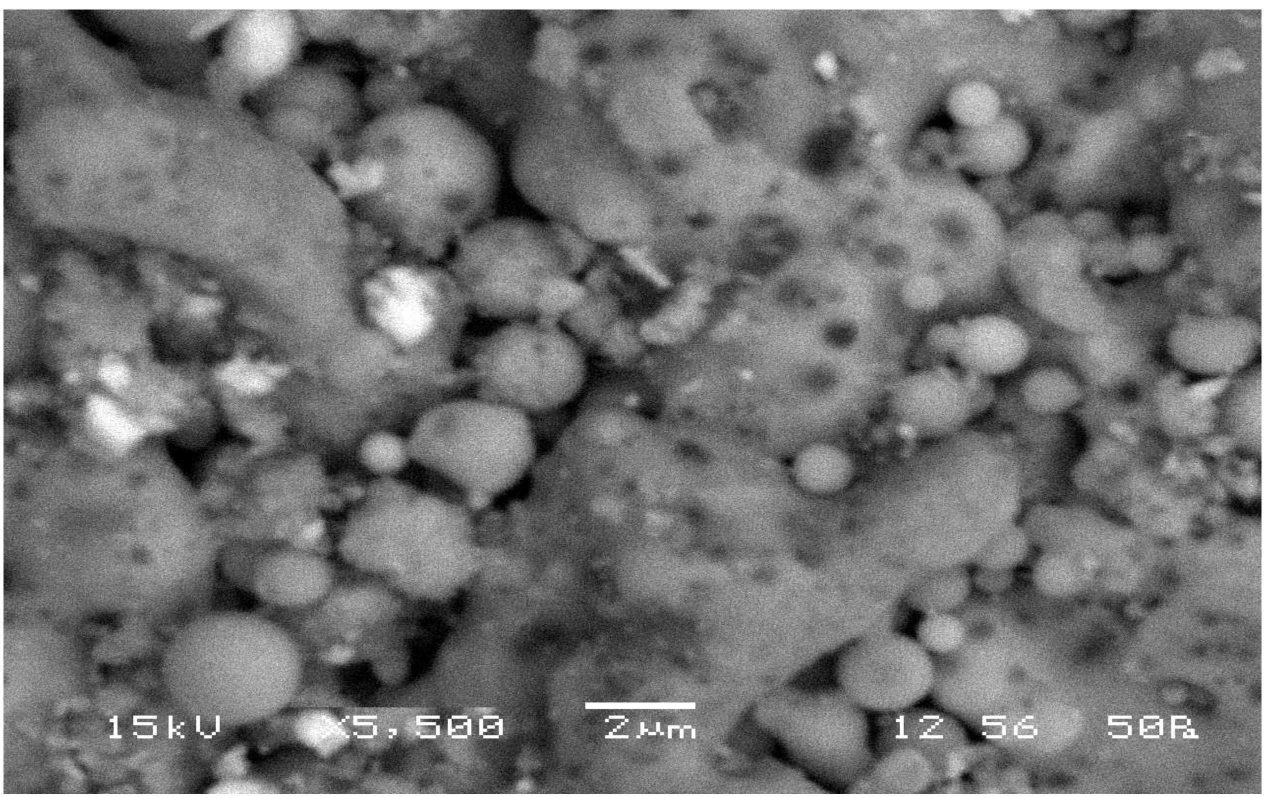


Fig 5.4.4 Particle Arrangement (SEM Photograph): 60% Red Mud + 40% Ash

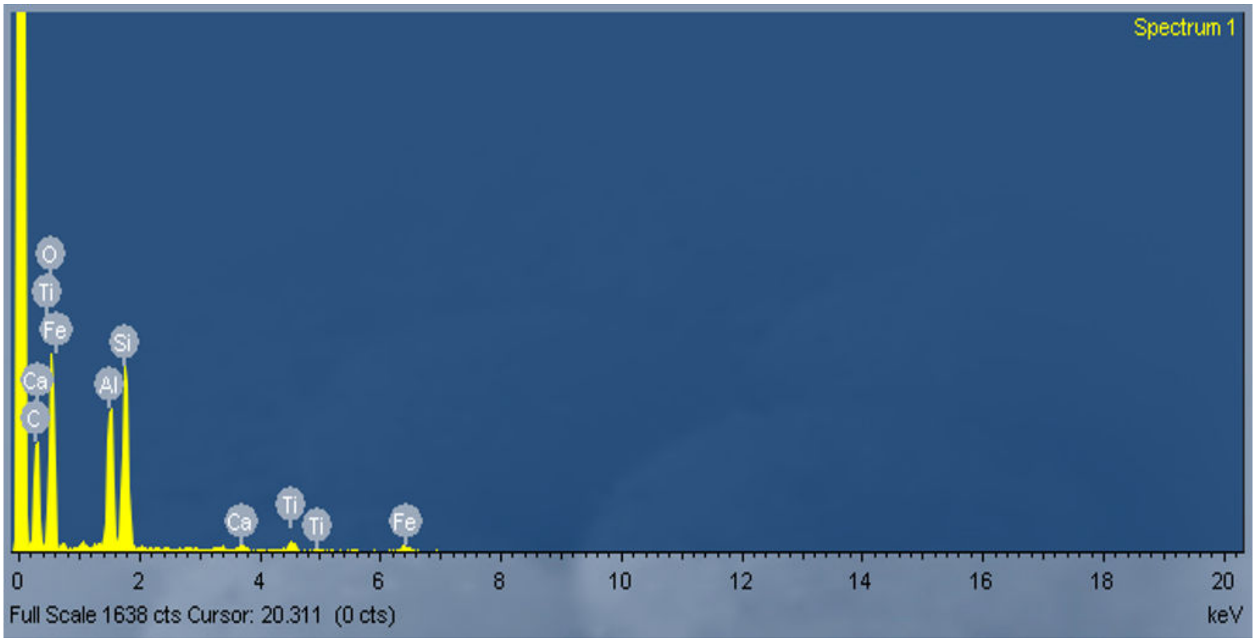


Fig 5.4.5 Mineralogy Analysis: 70% Red Mud + 30% Ash

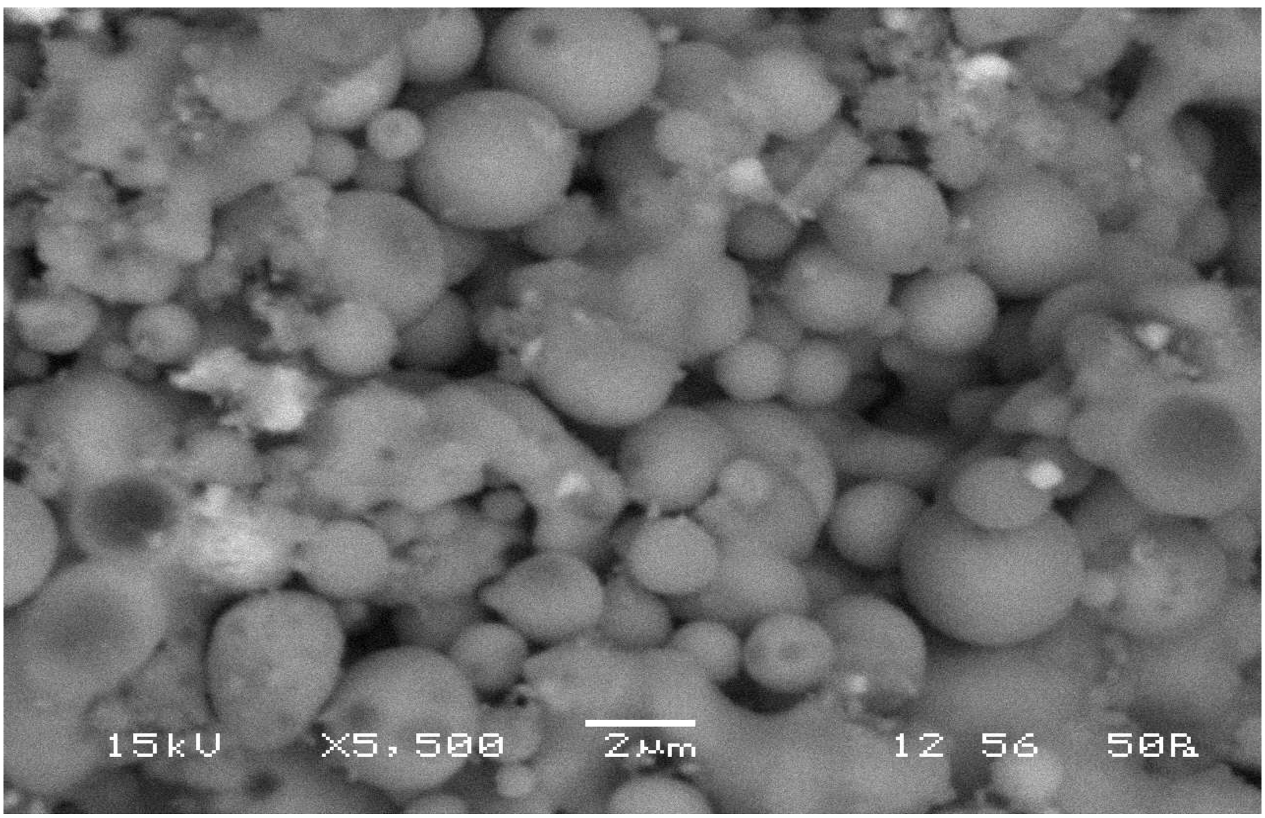


Fig 5.4.6 Particle Arrangement (SEM Photograph): 70% Red Mud + 30% Ash

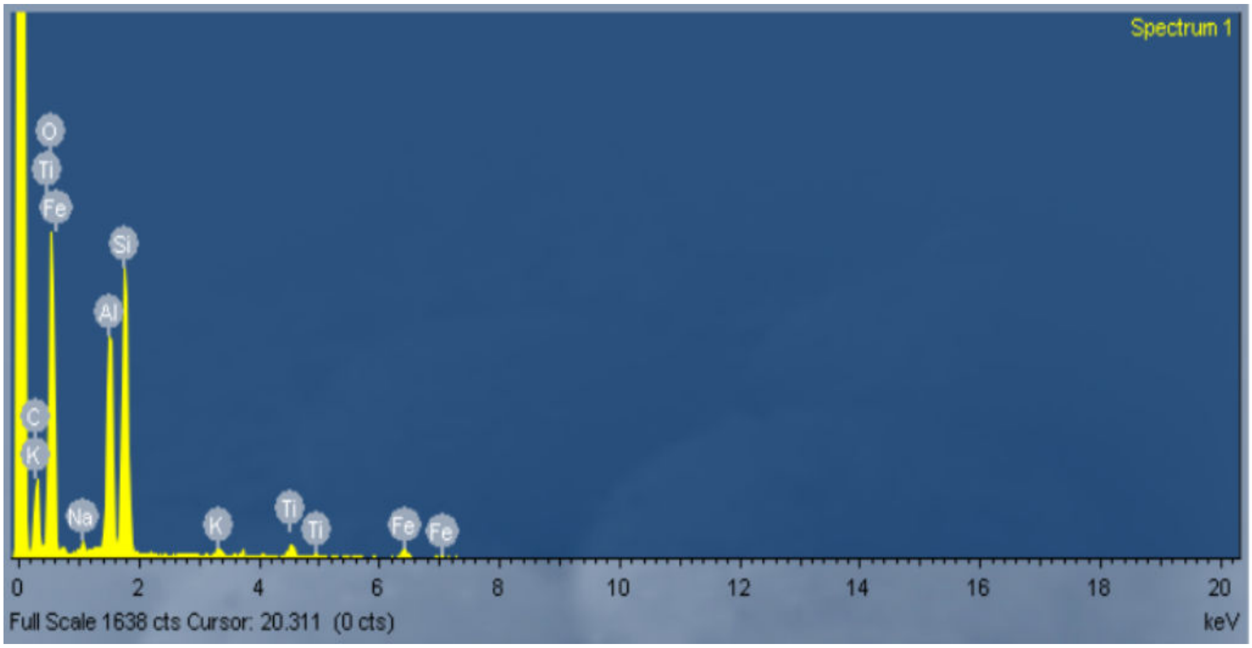


Fig 5.4.7 Mineralogy Analysis: 80% Red Mud + 20% Ash

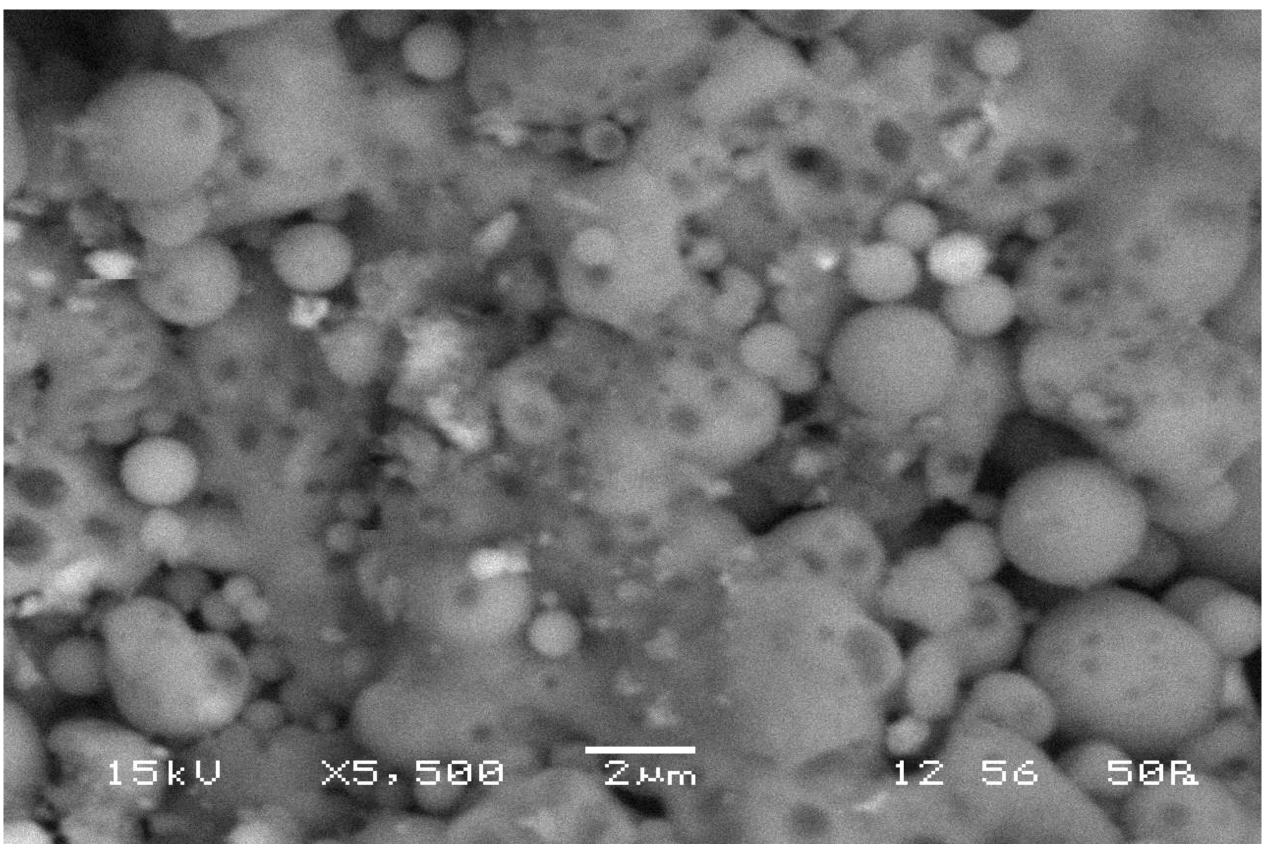


Fig 5.4.8 Particle Arrangement (SEM Photograph): 80% Red Mud + 20% Ash

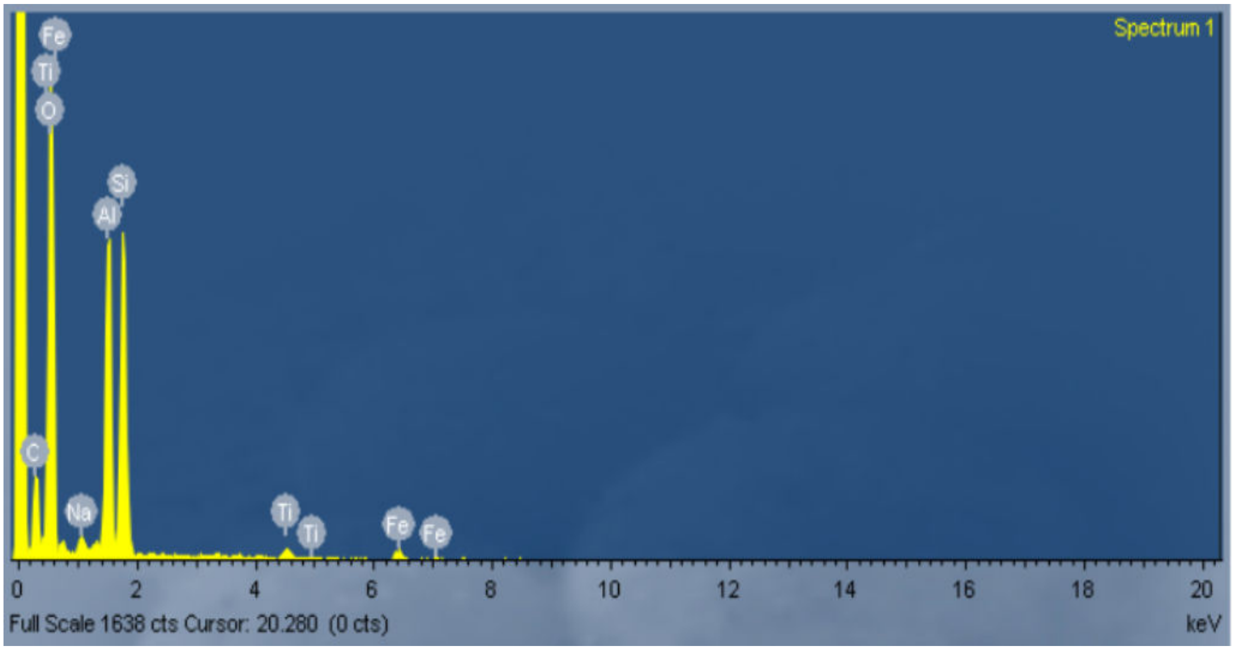


Fig 5.4.9 Mineralogy Analysis: 90% Red Mud + 10% Ash

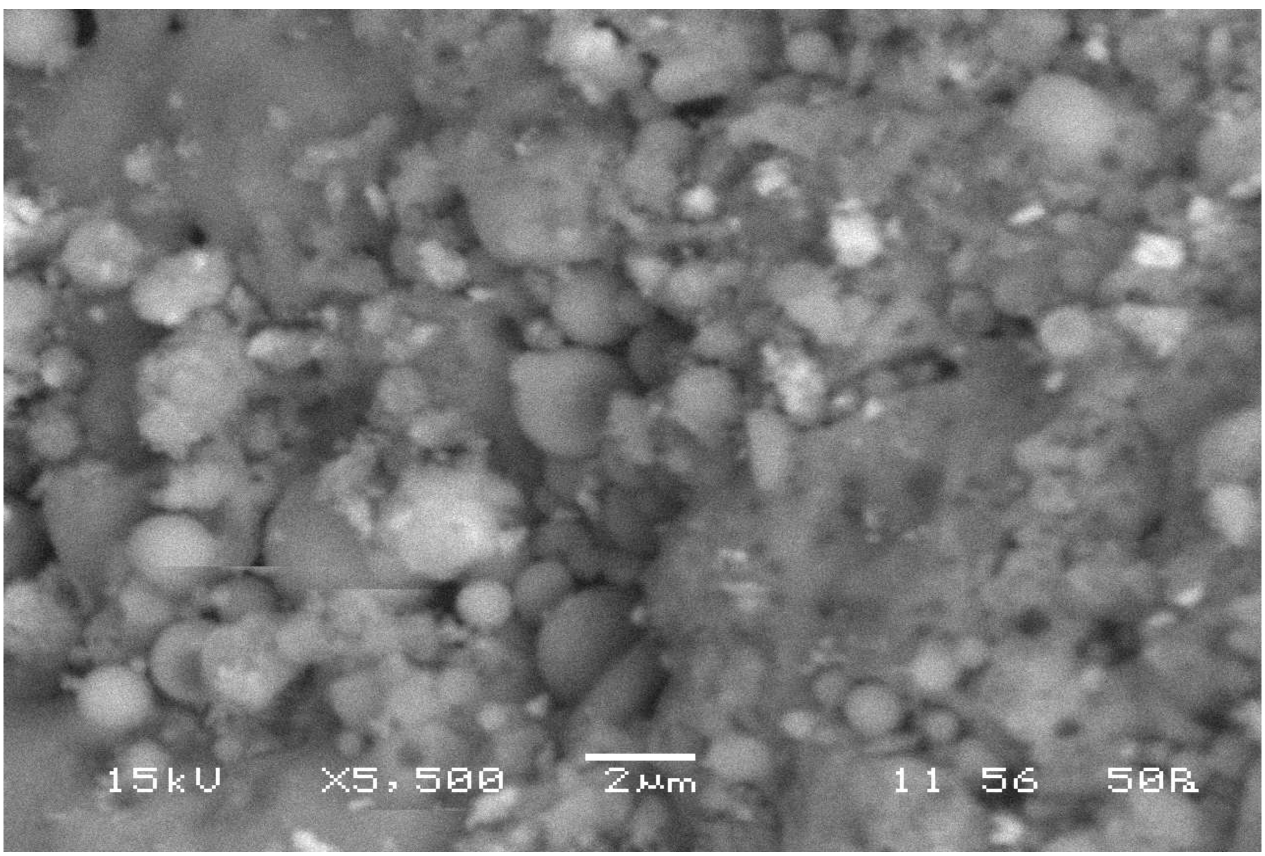


Fig 5.4.10 Particle Arrangement (SEM Photograph): 90% Red Mud + 10% Ash

CHAPTER 6

Analysis of Results

The trend of the following geotechnical properties of red mud and pond ash mixtures can be studied against the proportion of red mud in the mix:

6.1 Analysis of Maximum Dry Density (MDD)

Density of a body is determined by the mass contained in it per unit volume. Thus, dry density of a specimen is governed by:

i. Degree of compaction.
ii. Constituent minerals.
iii. Packing efficiency of particles.

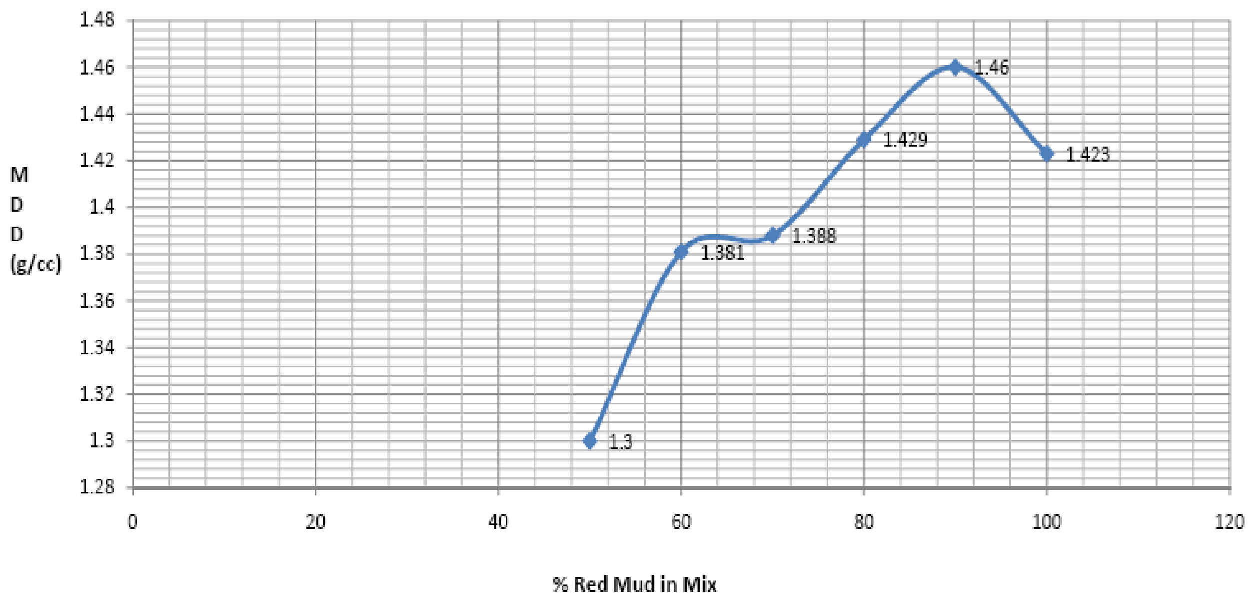


Fig. 6.1.1 Plot of MDD (g/cc) vs. % of Red Mud in Mix

As the MDD of the samples is obtained using Standard Proctor test, the compactive energy for all the specimens is constant. Now, from the mineralogy analysis of the samples of ash, red mud and various mixtures it is observed that proportion of Al and heavy elements (Fe, Ti and Si) increases as amount of red mud increases in the mixture (Heavy elements refer to the heaviness of the elements in terms of their density). From the bar chart representation of the mineral distribution in various mixes, it can be seen that the mixture having 90% ash and 10% ash has maximum of 37.81% of Al and heavy elements by weight.

Added, to these, due to better packing of the spherical ash particles in between the voids of the angular red mud particles, the packing efficiency of 90% red mud + 10% ash mixture increases. Due to maximum packing efficiency among all the mixtures, the MDD of this particular mix is obtained to be the maximum among all.

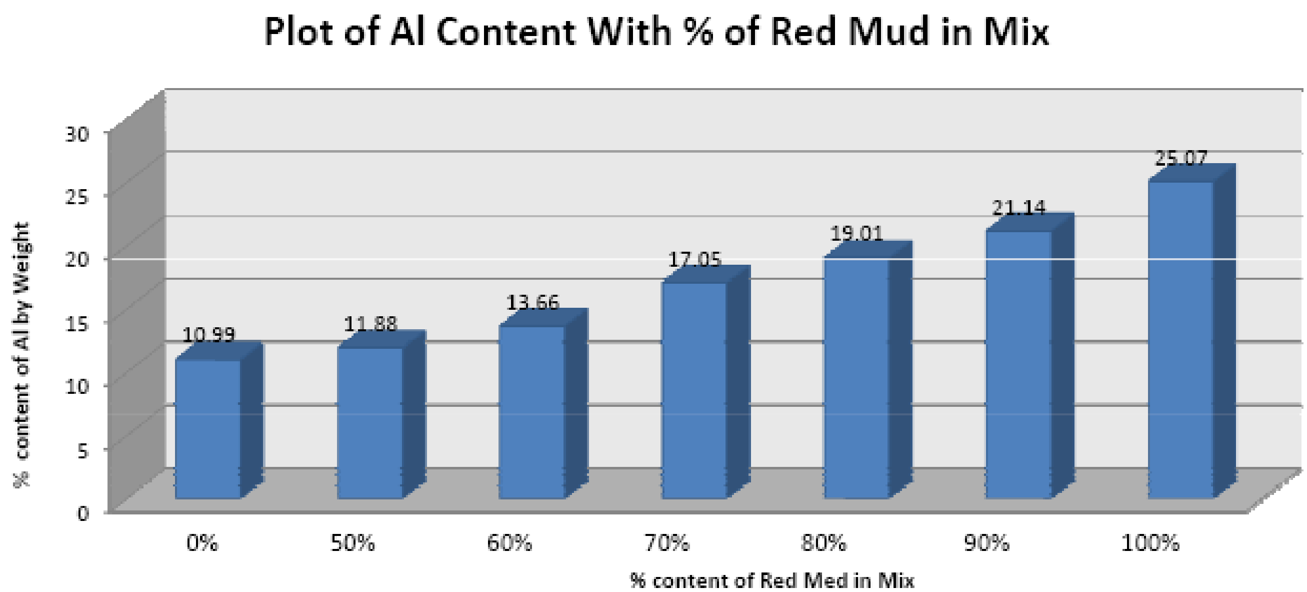


Fig. 6.1.2 Plot of Al Content (%) vs. % of Red Mud in Mix

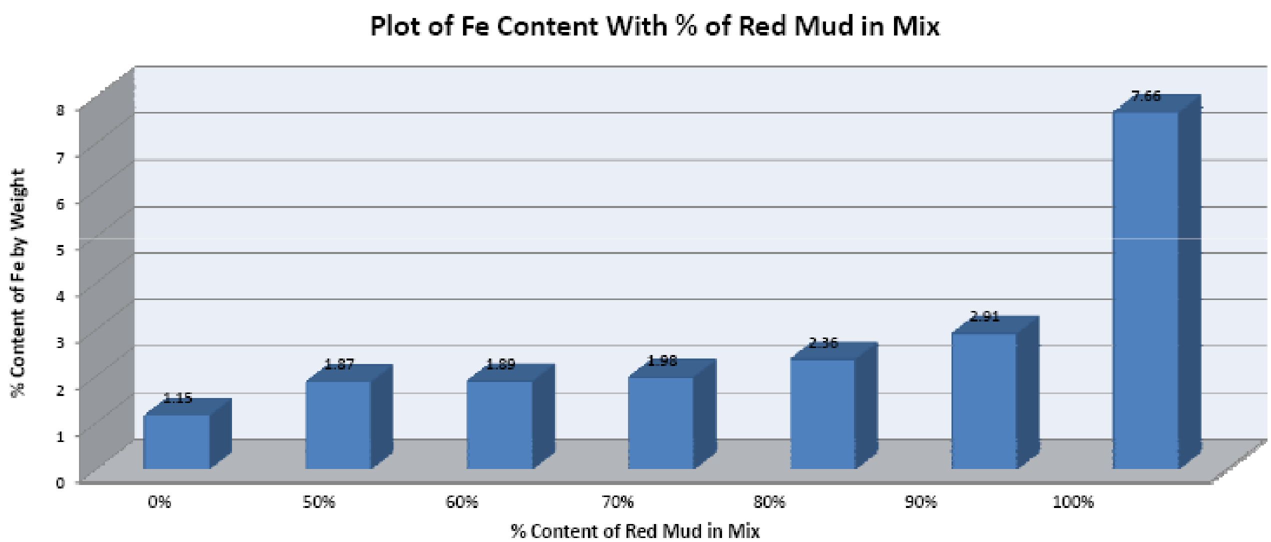


Fig. 6.1.3 Plot of Fe Content (%) vs. % of Red Mud in Mix

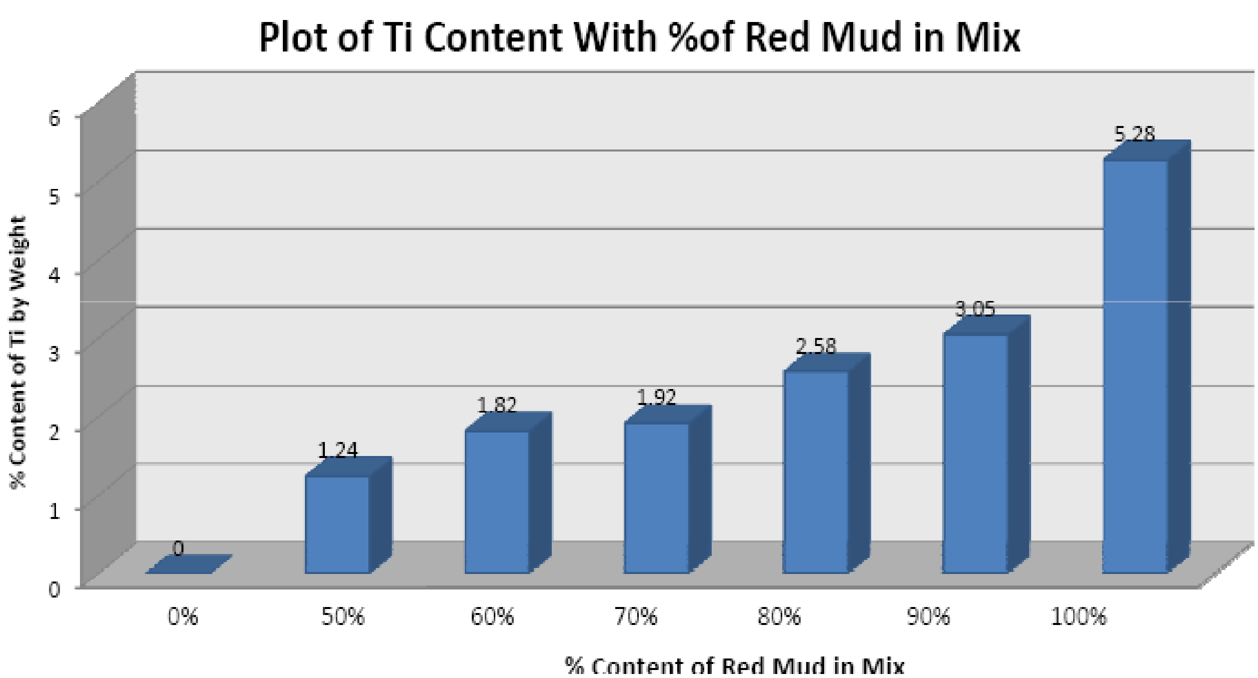


Fig. 6.1.4 Plot of Ti Content (%) vs. % of Red Mud in Mix

6.2 Analysis of Cohesive Strength

The trend shows maximum cohesion for a specimen containing 90% red mud + 10% pond ash (c = 8.8 KN/m^2) and it goes on progressively decreasing with reduction of proportion of red mud in the mixture (Fig. 6.2.1) .

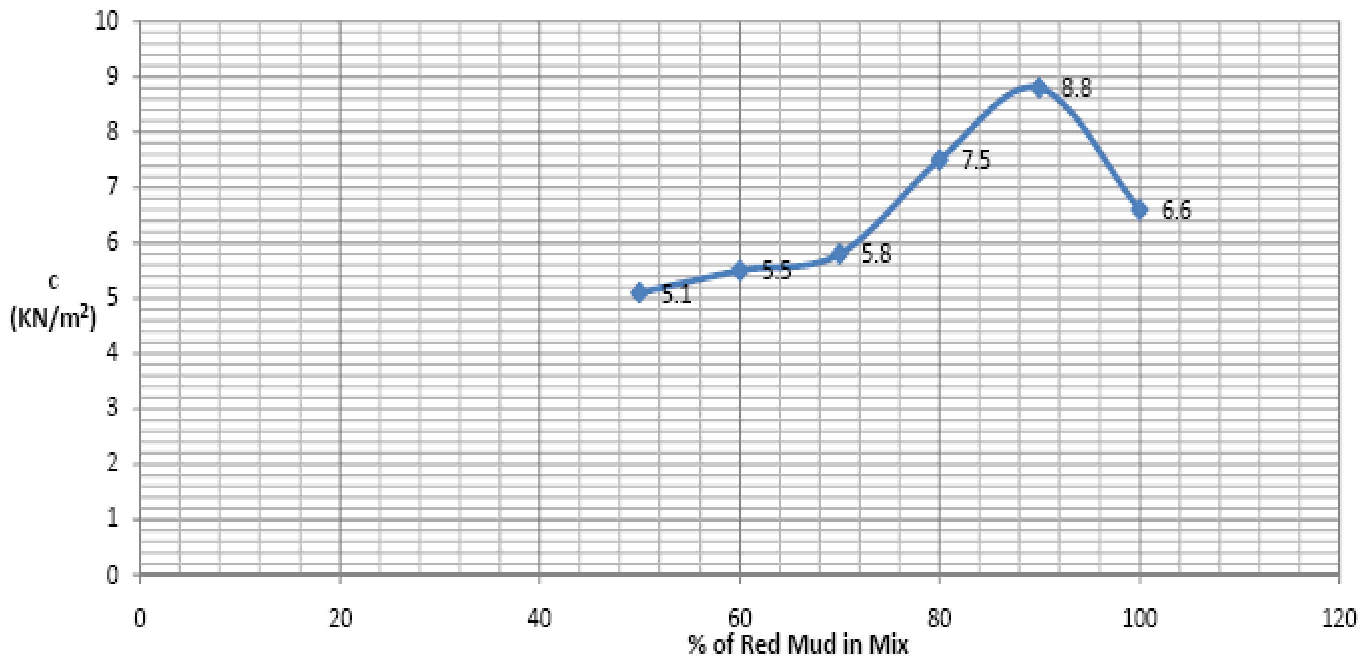


Fig. 6.2.1 Plot of Cohesive Strength (KN/m^2) vs. % of Red Mud in Mix

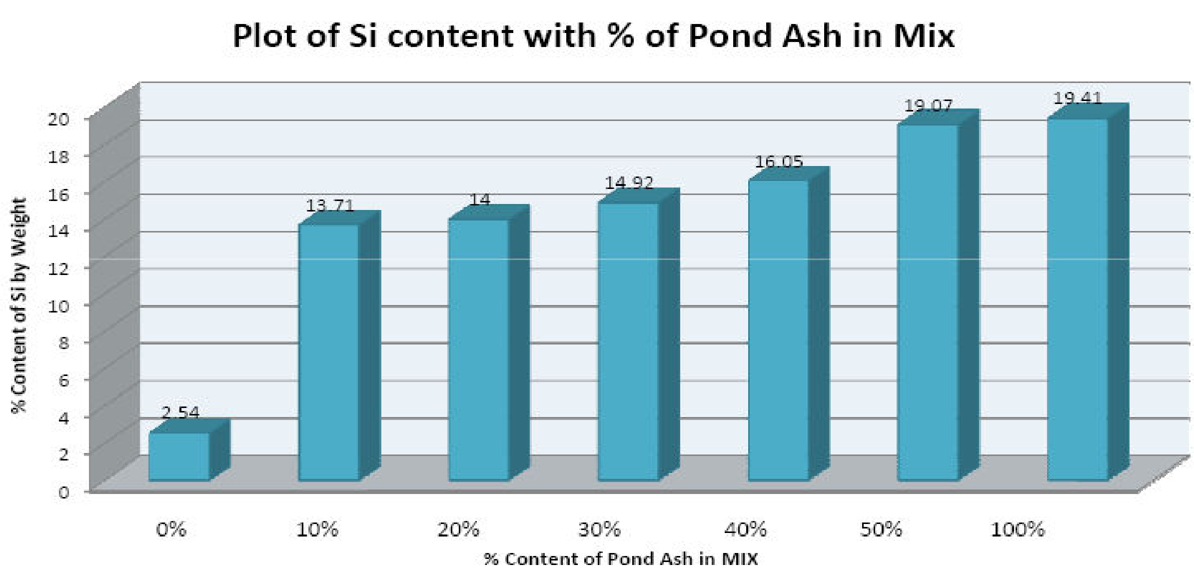


Fig. 6.2.2 Plot of Si Content (%) vs. % of Pond Ash in Mix

Cohesive strength is a surface characteristic. It depends on:

i. The intermolecular space between the particles
ii. The surface area to volume ratio of the particles in contact.
iii. Presence of elements capable of forming hydrogen bonds in presence of water.

Let us consider each of the above aspects one by one and analyze the above obtained the experimental results.

i. From the SEM photographs of the specimens, it is observed that the ash particles are more or less spherical in shape while the red mud particles are angular in shape. The surface texture of the ash particles are relatively smooth compared to that of red mud particles. Now, in case of specimen containing purely ash, by virtue of its spherical shape of particles, it has maximum intermolecular voids in between whereas on increasing the proportion of red mud the intermolecular voids goes on decreasing till it reaches minimum in case of 90% red mud and 10% ash mixture. Thus, maximum cohesive strength is obtained for that particular mixture. Again in case of 100% red mud, the intermolecular voids increase due to spaces left between the angular particles. Thus the cohesive strength falls a little.
ii. Taking into the second criteria, it is known that sphere has minimum surface to volume ratio. Thus, it has minimum contact area giving it a minimum cohesive strength. Whereas, due to rough surface texture, red mud particles attain a very high surface to volume ratio, thus we see a progressive increase in cohesive strength.
iii. From the mineralogical analysis, the element that can form hydrogen bond is only Si which can form H – Si – H bond. The hydrogen bonding in the presence of optimum moisture content aids in increasing the cohesive strength. Again the strength of hydrogen bond varies inversely with intermolecular spaces. The inter molecular spaces decrease starting from purely ash specimen to the mixture containing 90% red mud + 10% ash and again found to be increased for pure red mud specimen. Thus the maximum cohesive strength is optimum for mixture having proportion of 90% red mud and 10% ash.

6.2 Analysis of Angle of Friction, Φ

This is the principal parameter that governs the shear strength of a specimen. The value of Φ determines the intermolecular interaction. It depends mainly upon:

i. Arrangement of particles.
ii. Interlocking capability of constituent particles.

It is observed that the value of Φ is minimum for the specimen having pure pond ash (Fig. 6.3.1); it increases as red mud is mixed to it till it attains the maximum value for the mixture having 90% red mud and 10% ash, and again drops for specimen having purely red mud.

The above trend can be analyzed by again looking at the SEM photographs of the various mixtures. To start with, for the specimen having pure ash (Fig.3.7.2), due to its spherical shape and relatively smooth surface texture, it leaves lots of intermolecular voids and has weak interlocking ability between the particles. At higher shear loads, the weaker planes tend to slip off easily due to smooth texture into the nearest voids present.

On the other hand, in case of pure red mud (Fig. 4.7.2), due to its angular shape of particles and relatively rough surface texture, in spite of leaving intermolecular voids to some extent, it has stronger interlocking ability between the particles due to which it sustains higher shear load.

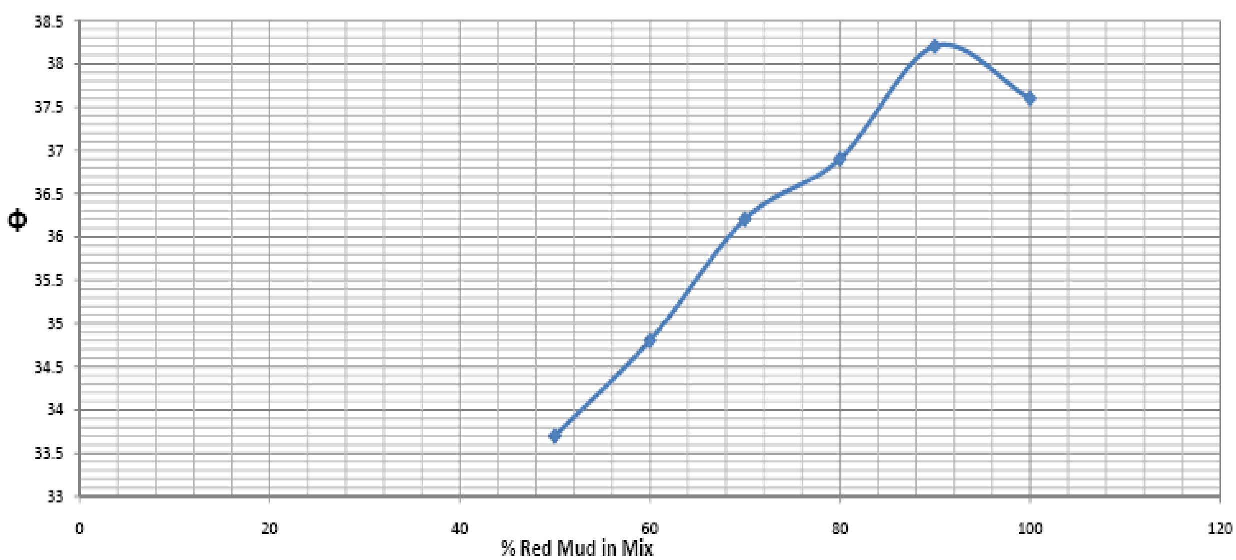


Fig. 6.3.1 Plot of Φ vs. % of Red Mud in Mix

In case of mixtures having ash and red mud in various proportions, the intermolecular voids are found to be the governing condition for the increase of shear strength. As seen from the SEM photographs (Fig. 4.7.2 and Fig. 5.4.10) again, for mixture having 90% red mud and 10% ash, the spherical ash particles fill up the voids left by the angular red mud particles under higher shear loads. Along with this, due to the rough texture of red mud particles, the ash particles filled up in the voids do not slip off easily under shear loads. Thus, the mixture having 90% red mud and 10% ash attains maximum shear strength.

Chapter 7

Conclusion

The present project can serve as a effective method to utilize the pond ash from thermal power plant and red mud residue from alumina plant. The strength parameters are the only governing criteria for stability of slopes for construction of embankments. Thus, the present analysis and results can serve the purpose of economical disposal of red mud and pond ash. From the analysis of mixtures of red mud and pond ash, mix proportion having 90% red mud and 10% pond ash shows a 10% rise in MDD over the mixture containing 50% red mud and 50% pond ash(1.3 g/cc for 50% red mud + 50% pond ash and 1.46 g/cc for 90% red mud + 10% pond ash). Also it shows a 72.5% increase in cohesive strength for 90% red mud and 10% pond ash over the mixture containing 50% red mud and 50% pond ash (5.1KN/m^2 for 50% red mud + 50% pond ash and 8.8KN/m^2 for 90% red mud + 10% pond ash). It also shows a 16% rise in angle of internal friction for 90% red mud and 10% pond ash over the mixture containing 50% red mud and 50% pond ash (33.7^0 for 50% red mud + 50% pond ash and 38.2^0 for 90% red mud + 10% pond ash). Hence, the mix proportion containing 90% red mud and 10% pond ash is the optimum mix that can be used for construction of embankments.The embankments can be constructed for the red mud ponds and ash ponds for disposal of the slurry in the respective ponds.

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APPENDIX I

Triaxial Test Observation Tables

Triaxial Shear Test
Sample: Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.6 kg/cm^2
= 58.8 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.6
300	10.8
350	13.2
400	15.8
450	19.2
500	22.4
550	25.8
600	27.2
650	31.6
700	34.4
750	37.8
800	41.8
850	46.6
900	51.2
950	58.4
1000	64.6
1050	68
1100	73.6
1150	76.4
1200	81.2
1250	85.6
1300	89.8
1350	91.6
1400	94.2
1450	99.4
1500	104.4
1550	105.2
1600	108.8
1650	110.4
1700	110.8
1750	111.4
1800	112.4
1850	114.8
1900	116.2

	115.6
	115.2

Here, total deformation = 18.5 mm = 1.85 cm .
Therefore,
Strain(e) = 1.85/ 9.4 = 0.20
Effective area, A = 20.43/(1-0.20) = 25.44 cm^2
Deviator load = 116.2 x 3.4 = 395.08 N
Deviator stress = 395.08/ 25.44. = 16.19 N/cm^2
= 161.9 KN/m^2
Hence, σ_1 = 161.9 + 58.8 = 220.7 KN/m^2
σ_2 = 58.8 KN/m^2

Triaxial Shear Test
Sample: Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.8 kg/cm^2
= 78.4 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	13.2
400	15.4
450	19.2
500	22.6
550	25.8
600	27.2
650	31.4
700	34
750	37.8
800	41.2
850	46.2
900	51.2
950	58.4
1000	64.6
1050	68.2
1100	73.2
1150	76.4
1200	81.2
1250	85.6
1300	89.8
1350	91.6
1400	94.2
1450	99.4
1500	104.2
1550	105.8
1600	109.8
1650	114.2
1700	117.2
1750	120.4
1800	122.6
1850	125.8
1900	128.4

1950	135.2
2000	139.2
2050	143.6
2100	149.5
2150	153.2
2200	158.3
2250	162.2
2300	165.4
	165.2
	163.4

Here, total deformation = 22.5 mm = 2.25 cm

Therefore,

Strain(e) = 2.25/ 9.4 = 0.24

Effective area, A = 20.43/(1-0.24) = 26.86 cm^2

Deviator load = 165.4 x 3.4 = 562.36 N

Deviator stress = 562.36/ 26.86. = 20.94 N/cm^2

= 209.4 KN/m^2

Hence, σ_1 = 209.4 + 78.4 = 287.8 KN/m^2

σ_2 = 78.4 KN/m^2

Triaxial Shear Test
Sample: Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 1 kg/cm^2
= 98 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	19.8
450	25.6
500	31.4
550	39.2
600	45
650	50.4
700	58.2
750	65.6
800	75.8
850	82.4
900	86.6
950	91.8
1000	96.6
1050	105.8
1100	110.8
1150	114.6
1200	119.6
1250	124.4
1300	132.2
1350	135.8
1400	139.6
1450	145.8
1500	148.2
1550	152.6
1600	156.2
1650	161.2
1700	167.6
1750	174.8
1800	179.2
1850	183.4
1900	186.2

1950	192.4
2000	194.2
2050	196.8
2100	199.6
2150	201.4
2200	203.4
2250	203.8
2300	204.4
	204.2
	203.6

Here, total deformation = 22.5 mm = 2.25 cm

Therefore,

Strain(e) = 2.25/ 9.4 = 0.24

Effective area, A = 20.43/(1-0.24) = 26.86 cm^2

Deviator load = 204.2 x 3.4 = 694.28 N

Deviator stress = 694.28/ 26.86. = 27.32 N/cm^2

= 273.2 KN/m^2

Hence, σ_1 = 273.2 + 98 = 378.2 KN/m^2

σ_2 = 98 KN/m^2

Triaxial Shear Test
Sample: Red Mud

Drainage condition: Unconsolidated Undrained
cell pressure = 0.6 kg/cm^2
= 58.8 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	19.8
450	25.6
500	31.4
550	39.2
600	45
650	50.4
700	58.2
750	65.6
800	75.8
850	82.4
900	86.6
950	91.8
1000	96.6
1050	99.8
1100	102.4
1150	110.2
1200	116.8
1250	124.4
1300	128.2
1350	134.4
1400	139.6
1450	145.8
1500	148.2
1550	152.6
1600	153.8
1650	154.4
1700	155.2
1750	159.6
1800	160.8
1850	162.2
1900	162.2

1950	163.4
2000	163.6
2050	165.2
2100	165.2
2150	165.4
2200	165.4
	165.2
	164.6

Here, total deformation = 21.5 mm = 2.15 cm

Therefore,

Strain(e) = 2.15/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 26.48 cm^2

Deviator load = 165.4 x 3.4 = 562.36 N

Deviator stress = 562.36/ 26.48. = 21.94 N/cm^2

= 219.4 KN/m^2

Hence, σ_1 = 219.46 + 58.8 = 278.2 KN/m^2

σ_2 = 58.8 KN/m^2

Triaxial Shear Test
Sample: Red Mud

Drainage condition: Unconsolidated Undrained
cell pressure = 0.8 kg/cm^2
= 78.4 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	29.4
500	34.6
550	42.8
600	49.4
650	58.8
700	67.2
750	75
800	82.2
850	89.8
900	95.4
950	100.2
1000	105.8
1050	111.6
1100	118.8
1150	128.4
1200	135.2
1250	141.6
1300	145.2
1350	151
1400	156.4
1450	162.8
1500	167.2
1550	171.2
1600	175.4
1650	180.2
1700	186.6
1750	192.8
1800	198.4
1850	202.4
1900	205.2

1950	208.4
2000	212.6
2050	215.8
2100	217.2
2150	222.2
2200	224.6
2250	224.8
2300	224.8
	224.4
	224

Here, total deformation = 22.5 mm = 2.25 cm

Therefore,

Strain(e) = 2.25/ 9.4 = 0.24

Effective area, A = 20.43/(1-0.24) = 26.86 cm^2

Deviator load = 224.8 x 3.4 = 764.32 N

Deviator stress = 764.32/ 26.86. = 29.46 N/cm^2

= 294.6 KN/m^2

Hence, σ_1 = 294.6 + 78.4 = 372.9 KN/m^2

σ_2 = 78.4 KN/m^2

Triaxial Shear Test
Sample: Red Mud

Drainage condition: Unconsolidated Undrained
cell pressure = 1 kg/cm^2
= 98 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	32.4
500	40.6
550	49.8
600	60
650	72.4
700	80.2
750	86.4
800	94.8
850	100.2
900	109.2
950	116.8
1000	121.4
1050	128.8
1100	137.4
1150	145
1200	154.2
1250	169.2
1300	174.4
1350	180.6
1400	198.4
1450	205.8
1500	214.2
1550	223.5
1600	238.6
1650	245.8
1700	249.8
1750	255.2
1800	258.2
1850	262.4
1900	265.2

1950	269.8
2000	273.4
2050	276.4
2100	280.2
2150	284.8
2200	289.6
2250	292.2
2300	293.2
2350	295.4
2400	297.2
2450	296.8
	296.6

Here, total deformation = 23.5 mm = 2.35 cm

Therefore,

Strain(e) = 2.35/ 9.4 = 0.25

Effective area, A = 20.43/(1-0.25) = 27.24 cm^2

Deviator load = 297.2 x 3.4 = 1010.48 N

Deviator stress = 1010.48/ 27.24 = 35.18 N/cm^2

= 351.8 KN/m^2

Hence, σ_1 = 351.8 + 98.0 = 449.8 KN/m^2

σ_2 = 98 KN/m^2

Triaxial Shear Test
Sample: Mixture of 50%Red mud and 50% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.6 kg/cm^2
= 58.8 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.6
300	10.8
350	13.2
400	15.8
450	19.2
500	22.4
550	25.8
600	27.2
650	31.6
700	34.4
750	37.8
800	41.8
850	46.6
900	51.2
950	58.4
1000	64.6
1050	68
1100	73.6
1150	76.4
1200	81.2
1250	85.6
1300	89.8
1350	91.6
1400	94.2
1450	99.4
1500	104.4
1550	105.2
1600	108.8
1650	110.4
1700	110.8
1750	111.4
1800	112.4
1850	114.8

1900	116.2
	115.6
	115.2

Here, total deformation = 18.5 mm = 1.85 cm .

Therefore,

Strain(e) = 1.85/ 9.4 = 0.20

Effective area, A = 20.43/(1-0.20) = 25.44 cm^2

Deviator load = 116.2 x 3.4 = 395.08 N

Deviator stress = 395.08/ 25.44. = 16.19 N/cm^2

= 161.9 KN/m^2

Hence, σ_1 = 161.9 + 58.8 = 220.7 KN/m^2

σ_2 = 58.8 KN/m^2

Triaxial Shear Test
Sample: Mixture of 50% Red mud and 50% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.8 kg/cm^2
= 78.4 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.6
150	4.2
200	5.8
250	9.8
300	10.6
350	15.2
400	18.4
450	21.2
500	25.4
550	29.4
600	32.2
650	35.8
700	37.6
750	42.2
800	48.8
850	53.8
900	59.8
950	62.2
1000	69.6
1050	71.4
1100	76.6
1150	80.2
1200	84.2
1250	87.6
1300	90.2
1350	95.2
1400	99.8
1450	104.2
1500	109.6
1550	114.8
1600	119.6
1650	124.2
1700	128
1750	132.4
1800	136.6
1850	138.8

1900	141.2
1950	145.2
2000	151.8
2050	154.6
2100	158.2
2150	163.4
2200	165.2
2250	166.8
	165.2
	164.6

Here, total deformation = 22.0 mm = 2.2 cm

Therefore,

Strain(e) = 2.2/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 26.77 cm^2

Deviator load = 166.8 x 3.4 =567.12 N

Deviator stress = 567.12/ 26.77 = 20.18 N/cm^2

= 201.8 KN/m^2

Hence, σ_1 = 201.8 + 78.4 = 280.2 KN/m^2

σ_2 = 78.4 KN/m^2

Triaxial Shear Test
Sample: Mixture of 50% Red mud and 50% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 1 kg/cm^2
= 98 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	30.6
500	37.4
550	45.4
600	58.8
650	67.6
700	72.4
750	80.4
800	89
850	98.4
900	102.2
950	116.8
1000	120.4
1050	126.8
1100	131.4
1150	136
1200	140.2
1250	146.2
1300	150.4
1350	154.8
1400	162.4
1450	167.4
1500	173.6
1550	177.4
1600	182.2
1650	191.2
1700	194.8
1750	198.5
1800	203.2
1850	210.4

1900	215.2
1950	219.8
2000	220.2
2050	220.6
2100	221.4
2150	221.8
2200	222.6
2250	222.6
	222.4
	221.2

Here, total deformation = 22.0 mm = 2.2 cm

Therefore,

Strain(e) = 2.2/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 26.77 cm^2

Deviator load = 222.6 x 3.4 = 754.54 N

Deviator stress = 754.54/ 26.77 = 26.03 N/cm^2

= 260.3 KN/m^2

Hence, σ_1 = 260.3 + 98 = 358.3 KN/m^2

σ_2 = 98 KN/m^2

Triaxial Shear Test
Sample: Mixture of 60%Red mud and 40% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.6 kg/cm^2
= 58.8 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.8
100	3.8
150	4.4
200	5.8
250	9.8
300	10.8
350	13.2
400	15.8
450	19.2
500	22.6
550	25.8
600	27.2
650	31.4
700	34
750	37.8
800	41.8
850	46.2
900	51.2
950	58.4
1000	64.6
1050	68.2
1100	73.6
1150	76.4
1200	81.4
1250	85.6
1300	89.8
1350	91.6
1400	94.2
1450	99.4
1500	104.2
1550	105.2
1600	108.8
1650	110.2
1700	110.8
1750	111.4
1800	112.6
1850	115.8

1900	116.2
	115.6
	115.2

Here, total deformation = 18.5 mm = 1.85 cm .

Therefore,

Strain(e) = 1.85/ 9.4 = 0.20

Effective area, A = 20.43/(1-0.20) = 25.44 cm^2

Deviator load = 116.2 x 3.4 = 395.08 N

Deviator stress = 395.08/ 25.44. = 16.19 N/cm^2

= 161.9 KN/m^2

Hence, σ_1 = 161.9 + 58.8 = 220.7 KN/m^2

σ_2 = 58.8 KN/m^2

Triaxial Shear Test
Sample: Mixture of 60% Red mud and 40% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.8 kg/cm^2
= 78.4 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	18.4
450	21.2
500	25.4
550	29.2
600	32
650	35.8
700	37.6
750	42.2
800	48.8
850	53.6
900	59.8
950	62.2
1000	69.6
1050	71.4
1100	76.6
1150	80.2
1200	84.2
1250	87.6
1300	90.4
1350	95.2
1400	99.8
1450	104.2
1500	109.6
1550	114.8
1600	119.6
1650	124.2
1700	128
1750	132.2
1800	136.6
1850	138.8

1900	141.2
1950	145.2
2000	149.8
2050	152.4
2100	155.8
2150	159.6
2200	162.2
2250	163.2
	163
	161.8

Here, total deformation = 22.0 mm = 2.2 cm

Therefore,

Strain(e) = 2.2/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 26.77 cm^2

Deviator load = 163.2 x 3.4 =555.26 N

Deviator stress = 555.26/ 26.77 = 19.20 N/cm^2

= 192.0 KN/m^2

Hence, σ_1 = 192.0 + 78.4 = 270.4KN/m^2

σ_2 = 78.4 KN/m^2

Triaxial Shear Test
Sample: Mixture of 60% Red mud and 40% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 1 kg/cm^2
= 98 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	30.6
500	37.4
550	45.4
600	58.8
650	67.6
700	6
750	80.4
800	89
850	98.4
900	102.2
950	116.8
1000	120.4
1050	126.8
1100	131.4
1150	136
1200	140.2
1250	146.2
1300	150.4
1350	154.8
1400	162.4
1450	167.4
1500	169.2
1550	181.4
1600	174.2
1650	176.8
1700	181.2
1750	182.6
1800	184.4
1850	187.2

1900	189.4
1950	189.6
2000	191.2
2050	192.8
2100	193.2
2150	193.4
2200	193.4
2250	193.4
2300	193.6
2350	193.6
2400	193.8
2450	194
2500	194
	193.8
	193.4

Here, total deformation = 24.5 mm = 2.45 cm
Therefore,
Strain(e) = 2.45/ 9.4 = 0.236
Effective area, A = 20.43/(1-0.26) = 28.77 cm^2
Deviator load = 193.4 x 3.4 = 657.56 N
Deviator stress = 657.56/ 28.77 = 22.86 N/cm^2
= 228.6 KN/m^2
Hence, σ_1 = 228.6 + 98 = 326.6KN/m^2
σ_2 = 98 KN/m^2

Triaxial Shear Test
Sample: Mixture of 70% Red mud and 30% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.6 kg/cm^2
= 58.8 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	18.4
450	21.2
500	25.4
550	29.2
600	32
650	35.8
700	37.6
750	42.2
800	48.8
850	53.6
900	59.8
950	62.2
1000	69.6
1050	71.4
1100	76.6
1150	80.2
1200	84.2
1250	87.6
1300	90.4
1350	95.2
1400	99.8
1450	104.2
1500	109.6
1550	114.8
1600	119.6
1650	124.2
1700	128
1750	132.2
1800	136.6
1850	138.8

1900	141.2
1950	145.2
2000	149.8
2050	152.4
2100	155.8
2150	159.6
2200	162.2
2250	163.2
	163
	161.8

Here, total deformation = 22.0 mm = 2.2 cm

Therefore,

Strain(e) = 2.2/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 28.77 cm^2

Deviator load = 163.2 x 3.4 =555.26 N

Deviator stress = 555.26/ 28.77 = 19.30 N/cm^2

= 193.0 KN/m^2

Hence, σ_1 = 193.0 + 58.8 = 252.1 KN/m^2

σ_2 = 58.8 KN/m^2

Triaxial Shear Test
Sample: Mixture of 70% Red mud and 30% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.8 kg/cm^2
= 78.4 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	30.6
500	37.4
550	45.4
600	58.8
650	67.6
700	72.4
750	80.4
800	89
850	98.4
900	102.2
950	116.8
1000	120.4
1050	126.8
1100	131.4
1150	136
1200	140.2
1250	146.2
1300	150.4
1350	154.8
1400	162.4
1450	167.4
1500	173.6
1550	177.4
1600	182.2
1650	191.2
1700	194.8
1750	198.6
1800	203.2
1850	210.4

1900	210.6
1950	211.2
2000	211.6
2050	212.4
2100	212.4
2150	212.6
2200	212.8
2250	212.8
	212.4
	211

Here, total deformation = 22.0 mm = 2.2 cm

Therefore,

Strain(e) = 2.2/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 28.77 cm^2

Deviator load = 212.8 x 3.4 = 723.52 N

Deviator stress = 723.52/ 28.77 = 24.84 N/cm^2

= 248.4 KN/m^2

Hence, σ_1 = 248. 4+ 78.4 = 326.6KN/m^2

σ_2 = 78.4 KN/m^2

Triaxial Shear Test
Sample: Mixture of 70% Red mud and 30% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 1 kg/cm^2
= 98 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	30.6
500	37.4
550	45.4
600	58.8
650	67.6
700	72.4
750	80.4
800	89
850	98.4
900	102.2
950	116.8
1000	120.4
1050	126.8
1100	131.4
1150	136
1200	140.2
1250	146.2
1300	150.4
1350	154.8
1400	162.4
1450	167.4
1500	173.6
1550	178.4
1600	184.6
1650	191.2
1700	194.8
1750	201.4
1800	206.4
1850	213.6

1900	219.8
1950	224.6
2000	229.2
2050	234.8
2100	238.8
2150	241.6
2200	246.8
2250	250.2
2300	253.4
2350	257.8
2400	260.3
2450	261.6
2500	262.8
2550	263.2
2600	263.2
	263
	262.6

Here, total deformation = 25.5 mm = 2.55 cm

Therefore,

Strain(e) = 2.55/ 9.4 = 0.27

Effective area, A = 20.43/(1-0.23) = 27.98 cm^2

Deviator load = x 3.4 = 894.88 N

Deviator stress = 894.88/ 27.98 =30.98 N/cm^2

= 309.8 KN/m^2

Hence, σ_1 = 309.8 + 98 = 407.83KN/m^2

σ_2 = 98 KN/m^2

Triaxial Shear Test
Sample: Mixture od 80%Red mud and 20% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.6 kg/cm^2
= 58.8 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.8
100	3.8
150	4.4
200	5.8
250	9.8
300	10.8
350	13.2
400	15.8
450	19.2
500	22.6
550	25.8
600	27.2
650	31.4
700	34
750	37.8
800	41.8
850	46.2
900	51.2
950	58.4
1000	64.6
1050	68.2
1100	73.6
1150	76.4
1200	81.4
1250	85.6
1300	89.8
1350	91.6
1400	94.2
1450	99.4
1500	104.2
1550	105.2
1600	108.8
1650	112.2
1700	116.2
1750	119.8
1800	120.4
1850	123.8
1900	124.8

	124.6
	123.4

Here, total deformation = 18.5 mm = 1.85 cm .

Therefore,

Strain(e) = 1.85/ 9.4 = 0.20

Effective area, A = 20.43/(1-0.20) = 25.44 cm^2

Deviator load = 124.8 x 3.4 = 424.32 N

Deviator stress = 424.32/ 25.44. = 18.68 N/cm^2

= 186.8 KN/m^2

Hence, σ_1 = 186.8 + 58.8 = 245.6 KN/m^2

σ_2 = 58.8 KN/m^2

Triaxial Shear Test
Sample: Mixture of 80% Red mud and 20% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.8 kg/cm^2
= 78.4 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	30.6
500	37.4
550	45.4
600	58.8
650	67.6
700	72.4
750	80.4
800	89
850	98.4
900	102.2
950	116.8
1000	120.4
1050	126.8
1100	131.4
1150	136
1200	140.2
1250	146.2
1300	150.4
1350	154.8
1400	162.4
1450	167.4
1500	173.6
1550	177.4
1600	182.2
1650	191.2
1700	194.8
1750	198.5
1800	203.2
1850	210.4
1900	215.2

1950	219.8
2000	220.2
2050	220.6
2100	221.4
2150	221.8
2200	222.6
2250	222.6
	222.4
	221.2

Here, total deformation = 22.0 mm = 2.2 cm

Therefore,

Strain(e) = 2.2/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 28.77 cm^2

Deviator load = 222.6 x 3.4 = 754.54 N

Deviator stress = 754.54/ 28.77 = 26.23 N/cm^2

= 262.3 KN/m^2

Hence, σ_1 = 262.3 + 78.4 = 340.6KN/m^2

σ_2 = 78.4 KN/m^2

Triaxial Shear Test
Sample: Mixture of 80% Red mud and 20% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 1 kg/cm^2
= 98 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	23.8
450	30.6
500	37.4
550	45.4
600	58.8
650	67.6
700	72.4
750	80.4
800	89
850	98.4
900	102.2
950	116.8
1000	120.4
1050	126.8
1100	131.4
1150	136
1200	140.2
1250	146.2
1300	150.4
1350	154.8
1400	162.4
1450	167.4
1500	173.6
1550	177.4
1600	182.2
1650	191.2
1700	194.8
1750	198.5
1800	203.2
1850	210.4

1900	215.2
1950	219.8
2000	226.6
2050	233.2
2100	236.8
2150	238.6
2200	242.4
2250	245.8
2300	248.6
2350	251.2
2400	254.8
2450	259.8
2500	260.2
2550	264.6
2600	266.2
2650	267.4
2700	267.8
2750	267.8
2800	267.8
	267.4
	265

Here, total deformation = 27.5 mm = 2.75 cm

Therefore,

Strain(e) = 2.75/ 9.4 = 0.29

Effective area, A = 20.43/(1-0.29) = 28.77 cm^2

Deviator load = 267.8 x 3.4 = 910.52 N

Deviator stress = 910.52/ 28.77 =31.65 N/cm^2

= 316.65 KN/m^2

Hence, σ_1 = 316.65 + 98.0 = 414.48 KN/m^2

σ_2 = 98.0 KN/m^2

Triaxial Shear Test
Sample: Mix of 90% Red Mud and 10% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.6 kg/cm^2
= 58.8 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.6
100	3.8
150	4.2
200	5.8
250	9.8
300	10.8
350	15.2
400	20
450	25.6
500	31.4
550	39.6
600	45
650	50.4
700	58.2
750	65.6
800	75.8
850	82.4
900	86.6
950	91.8
1000	96.6
1050	99.8
1100	102.4
1150	110.2
1200	116.8
1250	124.4
1300	128.4
1350	134.4
1400	139.6
1450	145.8
1500	148.2
1550	152.6
1600	153.8
1650	154.4
1700	155.2
1750	159.6
1800	160.8
1850	162.2
1900	162.4

1950	163.6
2000	163.8
2050	164.2
2100	165.2
2150	165.6
2200	165.6
	165.2
	164.6

Here, total deformation = 21.5 mm = 2.15 cm

Therefore,

Strain(e) = 2.15/ 9.4 = 0.23

Effective area, A = 20.43/(1-0.23) = 26.48 cm^2

Deviator load = 165.6 x 3.4 = 563.46 N

Deviator stress = 563.46/ 26.48. = 21.26 N/cm^2

= 212.6 KN/m^2

Hence, σ_1 = 212.6 + 58.8 = 271.42 KN/m^2

σ_2 = 58.8 KN/m^2

Triaxial Shear Test
Sample: Mix of 90% Red Mud and 10% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 0.8 kg/cm^2
= 78.4 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.4
100	3.8
150	4.4
200	5.8
250	10.1
300	10.8
350	15.2
400	23.6
450	29.4
500	34.4
550	42.8
600	49.2
650	58.8
700	67.2
750	75.2
800	82.4
850	89.8
900	95.4
950	100.2
1000	105.8
1050	111.4
1100	118.8
1150	128.4
1200	135.2
1250	141.6
1300	145.2
1350	151.2
1400	156.4
1450	162.8
1500	167.2
1550	171.2
1600	175.4
1650	180.2
1700	186.6
1750	192.8
1800	198.4
1850	202.4
1900	205.4

1950	208.4
2000	212.8
2050	215.8
2100	217.2
2150	222.2
2200	223.6
2250	223.8
2300	223.8
	223.4
	223

Here, total deformation = 22.5 mm = 2.25 cm

Therefore,

Strain(e) = 2.25/ 9.4 = 0.24

Effective area, A = 20.43/(1-0.24) = 26.86 cm^2

Deviator load = 223.8 x 3.4 = 760.92 N

Deviator stress = 760.92/ 26.86. = 29.06 N/cm^2

= 290.6 KN/m^2

Hence, σ_1 = 290.6 + 78.4 = 368.9 KN/m^2

σ_2 = 78.4 KN/m^2

Triaxial Shear Test
Sample: Mix of 90%Red Mud and 10% Ash

Drainage condition: Unconsolidated Undrained
cell pressure = 1 kg/cm^2
= 98 KN/m^2

Dial Gauge Reading	Proving Ring Reading
0	0
50	2.8
100	3.8
150	4.2
200	6.0
250	9.8
300	10.8
350	15.2
400	24.8
450	32.4
500	41.6
550	49.8
600	59.2
650	67.4
700	76.2
750	85.4
800	94.8
850	101.2
900	108.2
950	116.8
1000	121.4
1050	128.8
1100	137.4
1150	145
1200	154.2
1250	169.2
1300	174.4
1350	180.6
1400	198.4
1450	205.8
1500	214.2
1550	223.5
1600	238.6
1650	245.8
1700	251.8
1750	257.2
1800	264.2
1850	271.4
1900	276.2

1950	279.8
2000	283.4
2050	286.4
2100	290.2
2150	294.8
2200	296.6
2250	297.2
2300	297.2
2350	297.4
2400	298.2
2450	297.8
	297.6

Here, total deformation = 23.5 mm = 2.35 cm
Therefore,
Strain(e) = 2.35/ 9.4 = 0.25
Effective area, A = 20.43/(1-0.25) = 27.24 cm^2
Deviator load = 297.8 x 3.4 = 1012.58 N
Deviator stress = 1012.58/ 27.24 = 36.17 N/cm^2
= 361.7 KN/m^2

Hence, σ_1 = 361.7 + 98.0 = 459.8 KN/m^2
σ_2 = 98 KN/m^2